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Monterey, California

THESIS

AN INVESTIGATION OF THE MCDEC RESEARCH AND DEVELOPMENT PROGRAM PRIORITIZATION PROCESS

by

Laurence H. Nelson

September 1984

Thesis Advisor: Dan C. Boger

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are demonstrated with available process test data. The subjective research and development program values proposed by the original process are discussed in terms of measurement scale properties, and further research is suggested in the areas of alternative model forms, subjective program evaluations, and model implementation cost-benefit analysis.

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An Investigation of the MCDEC Research and Development Program Prioritization Process

by

Laurence H. Nelson
Captain, United States Marine Corps
B.S., University of Idaho, 1978

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requirements for the degree of

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I. INTRODUCTION

This thesis concentrates on the Marine Corps Development and Education Command, Research and Development Program Prioritization Process. The process was originally proposed to assist in developing the Marine Corps' input to the Navy's Research, Development, Test and Evaluation (RDT&E,N) Program Objective Memorandum (POM). The process combines subjective evaluations of the Marine Corps' identified mission deficiencies and proposed RDT&E programs, and produces a RDT&E program rank ordering according to mission deficiency accomplishment importance. The Department of Defense acquisition system is reviewed as it establishes the base for Marine Corps RDT&E program acquisition. Review of current acquisition procedures reveal that analytic models are used in support of the Procurement Marine Corps (PMC) POM but not for Marine Corps RDT&E,N POM input.

The literature concerning research and development program selection models is reviewed. The review shows that a wide range of program selection models are proposed and accepted by industry. The literature lends credence to the MCDEC process by allowing process classification with the majority of industry accepted models. Mathematical programming enhancement to this classification is suggested by the literature and is illustrated in this investigation. Linear programming formulations are used to duplicate the MCDEC process and suggest mathematical programming advantages under budget reduction conditions. A MCDEC produced process test data set is used to further illustrate the linear programming formulations. A second linear programming approach is suggested which concentrates on the number of mission deficiencies accomplished rather than the RDT&E

programs and presents a favorable program selection model alternative for the sample data set.

Further investigation is required to establish other possible alternatives suggested by the literature and for the implementation of a Marine Corps RDT&E program selection process. Further consideration of the costs associated with software, data collection, and manpower requirements will be necessary as well as comparing these costs with the benefits received from a process implementation.

II. BACKGROUND

A. INTRODUCTION

The Planning, Programming, and Budgeting System (PPBS) structures the defense systems acquisition procedure within the Department of Defense (DoD). This structure is a stepwise review and decision process conducted at various levels in the DoD hierarchy. The process translates validated defense mission needs into budget allocations which fund programs that are expected to overcome the stated needs. In this thesis the hierarchical level of concern descends from the Office of the Secretary of Defense (OSD), through the Department of the Navy (DoN), to the Marine Corps and the Navy. The analysis concentrates on the initial PPBS steps taken at this level, and specifically the Research, Development, Test, and Evaluation (RDT&E) acquisition program prioritization and funding profile process used by the Marine Corps.

B. SYSTEMS ACQUISITION IN USMC

1. Responsibilities

Specific responsibilities are assigned the Marine Corps by law.[1] Figure 2.1 depicts three levels of RDT&E and systems acquisition management that assist in accomplishing these responsibilities. The RDT&E and system acquisition responsibilities stated in MCO 5000.10A [Ref. 1] first designates the Assistant Commandant of the Marine Corps (ACMC) as the acquisition executive and then assigns him the responsibility for overall integration and unification of the management process. The Deputy Chief of Staff (DC/S) for Research, Development, and Studies (RD&S) assists the ACMC by acting as the coordinator of staff activities involved in RDT&E and system acquisition from program initiation to approval for service use. The Commanding General, Marine Corps Development and Education Command (CG, MCDEC) is the field representative of the Commandant of the Marine Corps (CMC) in RDT&E efforts and is responsible for the field execution and coordination of Marine Corps' RDT&E activities to support the systems acquisition. This includes coordinating Marine Corps support needs with other military services, as well as reporting on RDT&E efforts of other services, agencies, and governments.

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[1] The National Security Act of 1947, as amended, and subsequent DoD and SecNav directives assign the Marine Corps general and specific responsibilities for developing the tactics, techniques, and equipment used by amphibious landing forces. The Marine Corps is directed to coordinate and request appropriate assistance for this development with the Navy and other military services.

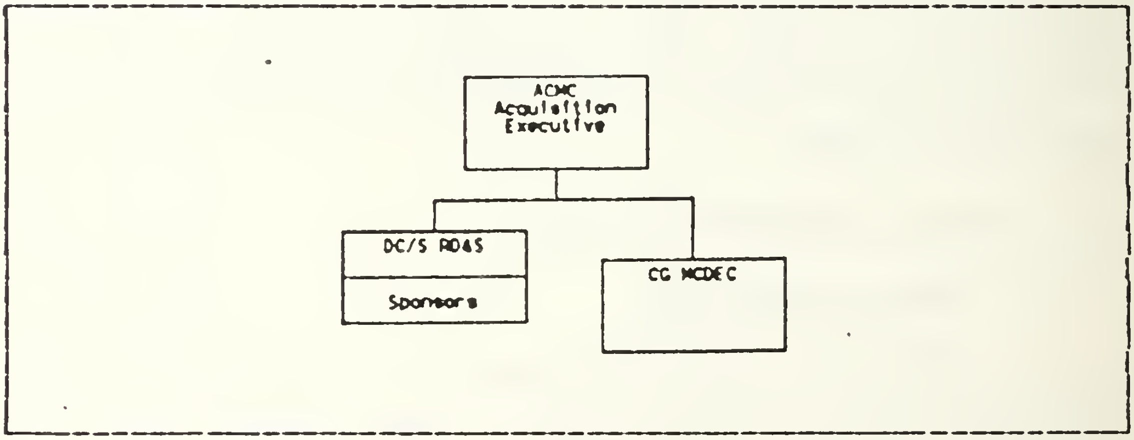

Figure 2.1 RDT&E and System Acquisition levels.

The deputy chiefs of staff or directors of major staff offices at Headquarters Marine Corps (HQMC) are assigned as program sponsors for specific Marine Corps mission areas and are intimately involved in the acquisition process. The program sponsors are responsible for the continuous analysis of their mission areas and the overall planning, coordination, and direction of related program acquisitions. These responsibilities are accomplished in coordination with DC/S RD&S and CG, MCDEC.

2. Analysis of Needs

The directed continual analysis of mission areas by the program sponsors, with input from the Fleet Marine Force (FMF), initially identifies operational mission needs. These needs, or equivalently mission deficiencies, are formally refined, additional needs identified, and related new concepts formulated by Mission Area Analysis (MAA). MAAs are assessments of current or projected Marine Corps capabilities within the specific mission areas and elements listed in Table I and are conducted by HQMC or MCDEC staff sections in coordination with the program sponsors and CG, MCDEC. The MAA details the mission elements of Table I into general operational missions and then further into specific operational missions. These specific missions can then be matched against specific resources for their accomplishment. If no resources are available then a deficiency is identified and recommendations for overcoming the deficiency are presented. SECNAVINST 5000.1A [Ref. 2] and "A Guide for the Performance of USMC Mission Area Analysis" [Ref. 3] detail the requirements and methodology of conducting MAAs. Each identified deficiency is formulated into a Justification for Major System New Start (JMSNS) or a Required Operational Capability (ROC) according to the Acquisition Category (ACAT). This documentation then forms the basis for initiating RDT&E funding and program acquisition.

TABLE I

Marine Corps Mission Areas and Elements

AREA	ELEMENT	TITLE
210		Land Warfare
	211	Close Combat
	212	Fire Support
	213	Ground Air Defense
	214	Mine Warfare
	215	Land Combat Support
	216	Land Combat Service Support
220		Air Warfare
	221	Counter Air
	222	Offensive Air
	224	Defense Suppression
	225	Air Warfare Support
230		Naval Warfare
	235	Amphibious Warfare
240		Tactical Nuclear Warfare
	243	Defensive Tactical N-Warfare
250		Theater and Tactical C^3I
	252	Tactical Command Control and Intelligence Systems
	255	Surveillance, Reconnaissance & Targets for Acquisition
	256	Tactical Communications
	257	Electronic Warfare & Counter C^3I
260		Mobility
	261	Airlift
	262	Sealift
	264	Refueling
320		Defense Wide C^3I Support
	321	Navigation & Position Fixing
	322	Support and Base Communication
	324	COMSEC
430		Non-System Training Devices
	431	Training Devices/Simulators
450		Test and Evaluation Support
	453	Joint Test and Evaluation
	454	Other Test and Evaluation
460		International Cooperative RDT&E
	461	Standardization & Interoperability
470		Management Support
	471	General Management Support
520		Exploratory Development
	521	Electronic & Physical Sciences
	522	Environmental & Life Sciences
	523	Engineering Technology

C. REVIEW AND DECISION PROCESS

1. Milestones

Four formal decision points are established within the program acquisition process and are designated milestones 0, I, II, and III. Positive approval is necessary at each milestone for passage of a program from conception to operational deployment. Milestone 0 signifies program initiation on approval of a JMSNS or a ROC. A favorable milestone I decision gives the approval to demonstrate selected alternatives. Then a milestone II approval authorizes full scale development and limited production for operational testing and evaluation. Finally, milestone III passage is necessary for production release and approval for service use. Marine Corps' input to the RDT&E,N Program Objective Memorandum (POM) is required throughout this process until milestone III, after which acquisition funding comes under the Procurement Marine Corps (PMC) POM.

2. Phases

The review steps of the acquisition process, shown in Figure 2.2 , are described as phases separated by the decision milestones. The initial reviews and analysis previously discussed are included in the first, or research phase. Studies and MAAs conducted in this phase identify mission deficiencies that, in turn, generate JMSNSs or ROCs. These documents assess the projected threat, state the mission element deficiency, identify the existing DOD capabilities, assess the impact of not acquiring or maintaining the capabilities, and finally provide a program plan to identify and explore competitive alternatives.

Approval of the JMSNS or ROC at milestone 0 moves the process from the research phase to the program initiation phase. The objectives of this phase include further

Phase	Objective	Funding
Research	Basic Science and Technology Research	6.1 Research
	MILESTONE 0	
Program Initiation	Paper Studies Technology Base Development	6.2 Exploratory Development
	MILESTONE I	
Demonstration Validation	Feasibility and Validity of Approach	6.3 Advanced Development
	MILESTONE II	
Full-Scale Development	Engineering Evaluation and Testing	6.4 Full-Scale Development
	MILESTONE III	
Production Deployment	Operational Hardware	6.6 Production Deployment

Figure 2.2 Marine Corps Acquisition Process Flow Chart.

program study and the development of a technological base to support the program through the remaining reviews and decisions. Tasks necessary to accomplish these objectives are program cost analysis, operational effectiveness studies, alternative identification, technical and economical feasibility studies, risk determination, and further concept and threat analysis. The primary documents produced during this phase are the System Concept Paper (SCP) for major programs or the Decision Coordinating Paper (DCP) for less-than-major programs. These documents summarize the program development to date and address mission element need, technology assessment, program description, management plan, and acquisition logistics and manpower.

Approval of the SCP or DCP at milestone I starts the demonstration and validation phase. Viable alternative systems and critical subsystems are subjected to competitive demonstrations during this phase. Tasks accomplished in conjuction with this phase include reviews of acquisition strategies, logistics, manpower and training planning, as well as the preparation of the test and evaluation master plan (TEMP). Major consideration is given to the thorough understanding of the operational need and the evaluation of all alternatives. Each alternative's unit cost goal, life cycle cost, technical feasibility, and economic realism is reviewed. When the demonstration and validation phase produces sufficient evidence that the preferred system can fulfill all necessary capabilities, and that technology exists to produce the system, the program sponsor recommends approval at milestone II.

A successfully passed milestone II initiates the full scale development (FSD) phase. This phase ensures that the engineering and production design, test and evaluation, personnel and training, and the integrated logistic support planning are completed prior to moving into production. Upon completion of all research and development through this phase, the approval for service use is given at milestone III. This decision to proceed starts the production and deployment phase and also designates the shifts of funding from RDT&E,N to PMC as well as the coordination responsibility from the DC/S RD&S to the Deputy Chief of Staff for Installations and Logistics.

3. Categories

All mission-essential acquisition programs in the Marine Corps are classified as either a major or less-than-major program. These two categories imply the level at which a milestone decision is made. Major programs are designated according to their funding level and other criteria, and may be assigned by the Secretary of Defense (SecDef), Secretary of the Navy (SecNav), or the Commandant of the Marine Corps (CMC). Department of Defense Instruction 5000.2 [Ref. 4], SECNAVINST 5000.1A [Ref. 2], and MCO 5000.10A [Ref. 1] list major program criteria used in these designations. Less-than-major programs are simply all other mission-essential acquisition programs not designated as major programs.

4. Review Councils

The level of hierarchy that designates a program as major also becomes the final decision authority for that program at milestones I, II, and III. The decision makers are supported by recommendations developed by the appropriate review councils which convene for these three milestones. The Defense System Acquisition Review Council (DSARC) and the Department of the Navy System Acquisition Review Council (DNSARC) provide program recommendations to the SecDef and the SecNav, respectively. Similarly, the Marine Corps System Acquisition Review Council (MSARC) supports the CMC on all major programs including those subject to higher review. The MSARC consists of a board of general officers, which is chaired by the ACMC and includes the CG, MCDEC, DC/S RD&S, and other major HQMC staff chiefs and directors. This council receives a comprehensive review of the research and development concerning the acquisition program and formulates recommendations for submission to the CMC.

The less-than-major programs undergo a similar review process by an In Process Review (IPR) Committee. This committee is chaired by the DC/S RD&S and has representation from all major HQMC staff and the CG, MCDEC. The ACMC is the decision authority for less-than-major programs, and the IPR committee submits recommendations to the ACMC for the acquisition program decision.

D. USMC RDT&E PROGRAMMING AND BUDGETING

All research, development, testing, and analysis described in this chapter depend critically on Congressionally-approved allocations. The estimation and submission of funding requests are coordinated by the DC/S RD&S for each fiscal year, and this process involves all Chiefs of Staff and Directors at HQMC. Initially each program sponsor must submit a prioritized listing and accurate funding estimate of his respective acquisition programs. The programs are then combined and subjectively prioritized and evaluated through a sequence of committees. The program sponsors present each proposal before a Program Evaluation Group (PEG) and then a POM Working Group (PWG). The groups' results are then reviewed and evaluated prior to submission to the CMC for approval. The approved acquisition program funding profiles levels are included in the Navy portion of the Five Year Defense Plan (FYDP) and become the

Marine Corps' input to the RDT&E,N POM. After DoN, DOD, and Congressional negotiations, Marine Corps RDT&E funds are appropriated by Congress as part of the RDT&E,N budget.

A similar cyclic process is involved in the development and submission of the PMC POM for the allocation of funds for the production and deployment phase after a positive milestone III decision. One difference between the two processes is the existence of an analytic support model used in the PMC process and the current absence of a support model for the RDT&E process. The model used during the PMC POM process was developed under civilian contract and is described in the final contract report, "Decision-Analytic Support of the USMC Program Development: A Guide to the Methodology" [Ref. 5]. Independent of the PMC model, the CG,MCDEC developed a process with the objective of combining many subjective judgements from headquarters and operational levels to prioritize RDT&E acquisition programs and provide suggestions in program funding profiles, however, this process has not been implemented.

E. THE PROBLEM

Defense system research and development programs individually do not possess an obvious numerical quantity that allows mathematically straightforward program comparisons or funding profile optimization. Inherent then to RDT&E program and funding decisions are the personal judgments of the decision maker. These subjective decisions rely on the information and analytic support available to the individual and supporting staff group prior to the decision. Marine Corps RDT&E acquisition programs are prioritized in upper hierarchical level committees and currently do not utilize mathematical analytical decision support. The increasing fiscal commitment associated with each new defense program and the intense competition for scarce resources imply the critical importance of prioritization decisions. To ensure presentation of the _best_ programs for funding allocations or to optimize the portfolio of programs presented will require assistance from analytical decision tools. The prioritization process proposed by MCDEC utilizes a model composed of linear combinations of normalized subjective weights. Other methods of multi-attribute analysis and models are suggested in the literature from industrial applications and theoretical techniques. Investigation into the RDT&E program prioritization process is warranted and may provide optimizing techniques which will assist the Marine Corps in RDT&E resource allocation and program selection.

III. LITERATURE REVIEW

A. INTRODUCTION

The importance of Research and Development (R&D) in the private and governmental sectors is evident from the quantity of information available in professional papers, journals, and books. This chapter reviews a portion of this literature which concentrates on R&D project selection and resource allocation models, the suggested utilization of these models, their limitations, and their acceptability. The purpose of this review is to investigate demonstrated or proposed methods of solving a problem similar to that previously presented and should not be viewed as an exhaustive study of R&D literature.

Several published articles review a number of proposed methodologies and models in the R&D project selection and resource allocation area. These review articles tend to classify model forms into one of two general categories. Baker [Ref. 6] titled the categories as "benefit measurement" and "project selection and resource allocation." Winkofsky, et al. [Ref. 7] described similar classifications as "value measurement" and "portfolio selection." Benefit or value measurement models rely on subjective expert judgement for project evaluation combined into checklists, comparative project scores, or economic indices. Project or portfolio selection and resource allocation models normally use a mathematical programming or other optimizing technique to maximize a benefit, such as profit, subject to constraints, such as budget and manpower. Other articles, Augood [Ref. 8], Gear, et al. [Ref. 9], Gear [Ref. 10], Newman [Ref. 11], and other authors review or propose models that can be classified into these general categories. Benefit measurement and portfolio selection will be used for model classification in this review.

Some authors, Winkofsky, et al. [Ref. 12], Baker, et al. [Ref. 13], and Allen, et al. [Ref. 14], propose methodologies for implementing series of models for hierarchical applications. In addition to the model and methodology proposal and review articles, Brandenburg [Ref. 15], Baker [Ref. 6], Souder [Ref. 16 and 17], and other authors suggest R&D model analysis criteria as well as observed model limitations and acceptability.

B. RESEARCH AND DEVELOPMENT MODELS

In addition to the general classifications of benefit measurement and portfolio selection, models are further defined by a common form, such as an index model or a linear programming model, a description of that form, and the recommended or observed use of the model.

1. Benefit Measurement Models

Benefit measurement models typically use subjective evaluation of a number of R&D project attributes and combine these evaluations into a project value or worth. These models are classified into the checklist, scoring and index model forms.

a. Checklist Models

These models are the simplest type and use subjective comparisons of a project against a list of elements. The elements describe project criteria or considerations, established by the management, that have some significance towards success. Augood [Ref. 8] suggests five general criteria subdivided into 53 specific elements.

Cooper [Ref. 18] surveyed 103 industrial product firms and was able to analytically reduce his 48 similar elements into 13 meaningful factors. Augood [Ref. 8] also suggests rating projects against the checklist elements by using descriptors such as very unfavorable, unfavorable, average, favorable, and very favorable. The worth of a project is provided by observing the number of criteria it meets or how "favorable" the project looks by its overall element descriptor ratings. This method then requires judgemental evaluations of the checklist results for each project. Winkofsky, et al. [Ref. 7] in their literature review, observed that checklist models are most suitable for project evaluation in the exploratory R&D phase when only preliminary project information is available.

b. Scoring Models

Scoring models are quantified extensions of the checklist models and provide a numerical score or value for each project. Using a similar criteria list as used in the checklist models, the project score is typically generated from products of assigned criteria weights and project values associated with criteria accomplishment. These products are then summed over all criteria to provide the final project score. Winkofsky, et al. [Ref. 7] presented the general scoring model form as

$$PVj = Sum/i \, [(Wi) (Sij)] \qquad (3.1)$$

where,

i = criterion number,
j = project number,
PVj = jth project value to organization,
Wi = ith criteria or element weight, and
Sij = jth project accomplishment of the ith criterion.

The weights such as Wi or Sij are normally assigned by R&D managers or R&D advisory groups based on personal or group judgement. Cooper [Ref. 18] empirically derives criteria weights through subjective survey data and a multivariable regression. Augood [Ref. 8] suggested applying the weights 0, 2, 5, 8, and 10 to his five increasing benefit element descriptors and subjectively assigning relative importance weights to each element. He then represented a project score as

$$PVj = (100\ \mathrm{Sum}/i\ [\ (Wi)\ (Sij)\ ])/(10\ \mathrm{Sum}/i\ [\ Wi\ ]) \qquad (3.2)$$

where the previous notation of equation 3.1 is used. This form bounds the score between 0 as failure to 100 as success. Scoring models have been used for project selection in a number of organizations, according to Winkofsky, et al. [Ref. 7], with various criteria and weighting schemes utilized.

c. Index Models

These models directly involve probability of project success and costs. The general form of an index model is;

$$I = (P)(B)\ /\ C \qquad (3.3)$$

where,

I = project index value,
P = project probability of success,
B = project benefit, and
C = cost.

The differences in the index models proposed in the literature are determined by what is included in the three model parameters. The probability of success may include subfactor probabilities such as success in research, technology, production, and market areas. Benefits include items such as savings, profits, or cash flow. Costs range from R&D investment to total lifecycle expenditures. These indices may be used alone or combined into other indices to provide the final project measurement such as the Ansoff index, suggested by Winkofsky, et al. [Ref. 7] as typical of R&D project selection indices. Ansoff's index provides a numerical value called the Figure of Merit (FM) such that

$$FM = rdp(T + B)E \,/\, (\text{Total investment}) \qquad (3.4)$$

where,

r = probability of research success,
d = probability of development success,
p = probability of market success,
T = index of technical merit,
B = index of business merit, and
E = present value of earnings from project.

Like the scoring models, the index models combine a number of project attributes into a single value which may then be used to rank projects and assist in determining project selection. More cost analysis is required for typical index models than is generally necessary for scoring models.

2. Portfolio Selection Models

Portfolio selection models are normally more complicated than benefit measurement models; however, they also provide additional flexibility and realism to the R&D decision maker, according to Souder [Ref. 17]. Typically these models utilize a mathematical programming technique to assist in project selection by providing the resource allocation that will maximize the benefit contribution for a set of possible projects. The models are classified within the portfolio selection category by the mathematical programming form used. Linear, non-linear, integer, and dynamic programming model forms have been proposed in literature. Winkofsky, et al. [Ref. 7] observed in their review that these portfolio selection models assume that an explicit benefit or contribution function can be determined. They reviewed other authors, however, that utilize an interactive programming model form which assumes an implicit benefit function exists but is never formally defined.

a. Linear Programming

The general form of the linear programming model is

$$\text{maximize} \quad cx \qquad (3.5)$$

$$\begin{aligned} \text{subject to} \quad & Ax \le b \\ & 0 \le x \le 1, \end{aligned}$$

where,

x = n-component project resource allocation vector,
c = n-component project benefit vector,
A = mxn-component project resource utilization matrix, and
b = m-component available resource allocation vector.

Linear programming computations provide an optimal resource allocation for all projects provided that the values represented by c, b, and A can be explicitly obtained and the assumed linear relationships between resources and benefits portray an accurate model of the using organization's situation. The project resource allocation vector x, provided by the computations, takes values between and including zero and one. Zero represents no resource allocated on that specific project and a one represents full allocation. Values between zero and one provide the proportion of full resource allocation necessary for the optimal solution. Asher [Ref. 19] proposed a linear programming model to allocate manpower teams involved in the testing operation of new chemical compounds under development by a pharmaceutical company. The project resource allocation vector represented the number of tests of a specific compound each team would conduct and was bounded by the total number of each chemical compound available.[2] The expected return of the compound to the firm was used as the the project benefit vector and was calculated as the product of the probability of success and the estimated net market value of success for each compound. The project resource utilization matrix was equal to the number of hours necessary for each team to test a specific compound and was based on the team's experience and skill levels. The resource vector was the manhours available for each team. The computation results provided which manpower team should test which compound and the quantity of that compound they should test in order to maximize the expected value of return to the company.

b. Non-linear Programming

Non-linear programming models are very similar to the linear models but attempt to represent reality as non-linear relationships rather than strictly linear. Non-linear models are formulated with similar notation as equations 3.5 and provide similar resource allocation information. A non-linear benefit function has the intuitive appeal that as more units of resource are provided to a project less benefit is returned for each additional input unit. Chidambaram [Ref. 20] considered three separate concave nondecreasing functions; quadratic, exponential, and logarithmic; which all approximated his U.S. Army data of estimated future military benefits for a set of projects. Souder [Ref. 16] proposed and analyzed four portfolio selection models based on similar models in the literature using thirty actual R&D projects. For his model Souder used two types of non-linear benefit functions which are represented by Figures 3.1 and 3.2. The exponential type, Figure 3.1, is also similar to Chidambaram's benefit functions. Souder suggests using this type of function when incremental resource expenditures in the lower x domain are expected to greatly increase the return, and the benefit diminishes at some point as resource levels are increased. The S-shaped benefit function, Figure 3.2, was suggested for project cases where success was related to a breakthrough in technology. In this case the return from the resource input was initially expected to be lower until the breakthrough. Then, small additional resource expenditures returned larger benefits until a diminishing return point is reached.

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[2] The bound of one was previously noted for the typical linear program model. Asher's computations found the actual allocation value enstead of a proportion.

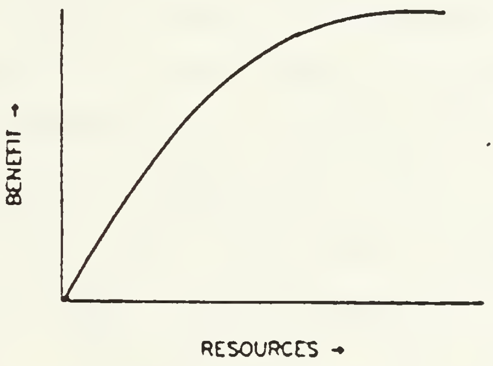


Figure 3.1 Exponential Type of Benefit Function.

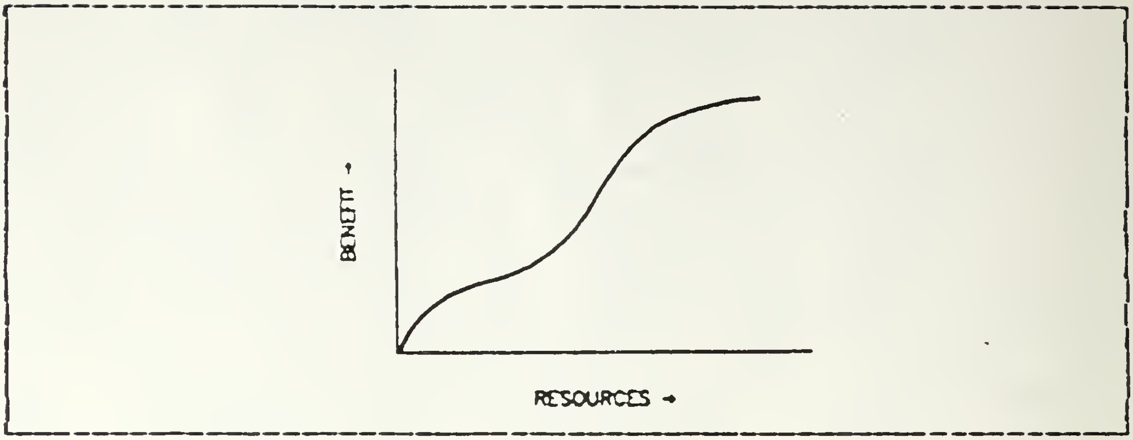


Figure 3.2 S-Shaped Type of Benefit Function.

c. Goal Programming

Goal programming is a mathematical programming method which incorporates several objective functions as organizational goals and attempts to solve them simultaneously. The objective or goal functions become the constraints of a linear or non-linear programming problem. The problem's overall objective function is a composite of the goal functions which are weighted in their relative accomplishment importance by the program user. The computation minimizes the prioritized deviations from the goal constraints as described by the composite objective function and defines a range of feasible solutions between the competing goals. Goal programming in R&D models is normally used with other model forms such as in Taylor, et al. [Ref. 21] and Winkofsky, et al. [Ref. 12].

d. Integer Programming Models

Integer programming models are formulated in a similar manner to the linear and non-linear models, however the project resource allocation vector is constrained to be integers only. Taylor, et al. [Ref. 21] utilized an integer program model incorporating goal programming methods to allocate thirty researchers among seven R&D projects. Non-linear constraints were used to relate the number of researchers assigned to a project to probability of success, monetary return, and project time completion. Linear constraints were used to describe budget limitations and computer capacity utilization. A linear composite objective function was used that described prioritized deviations from each goal constraint and the integer program computation minimized these deviations to provide the optimal allocation solution. Other authors have proposed simpler 0-1 integer program models which provide a go or no-go project decision depending on the resource allocation vector values of one or zero respectively.

e. Dynamic Programming Models

The first three portfolio selection model forms described are closely related and differ only in the benefit and constraint functional relationships and the domain of the resource allocation vector. A dynamic programming approach to R&D project selection provides a different optimizing technique with a sequential decision process. Hess [Ref. 22] presents such an approach as more typical of the R&D budgeting problem than a current-cycle-only optimizing solution. Hess suggests that most R&D resource allocation models do not adequately consider the periodic re-evaluation of R&D projects which stem from the increase in information obtained during the R&D process as well as the cyclic budgeting evolution. Hess proposed using the mathematical recursive technique of dynamic programming to develop an optimal resource allocation policy, Po, for the series of subsequent project resource decisions stages. The general recursive equations for Hess' model are

$$f1(x) = \max \text{ over } P\ [\ R1(x,P)\ ] \tag{3.6}$$

for the last decision, and

$$fn(x) = \max \text{ over } P\ [\ Rn(x,P) + fn-1\{xn-1(x,P)\}\ ] \tag{3.7}$$

for the nth prior decision where,
$fn(x)$ = maximum benefit when n decisions remain,
x = initial quantity of resource,
P = policy or series of resource decisions used,
$xn-1(x,P)$ = resource function of x and P at stage n-1, and
$Rn(x,P)$ = benefit returned in stage n using x and P.

Assuming $Rn(x,p)$ is known through some benefit measurement method, the optimal policy, Po, is calculated by first solving equation 3.6 for the last decision, stage 1. Next, equation 3.7 is solved for $n=2$ with the substitution of equation 3.6 The value of n is increased and equation 3.7 is solved again with the substitution of the n-1 results. Each incremental increase in n represents the next prior decision stage in the sequential R&D resource allocation process. The dynamic programming model is dependent on knowing the benefit values of $Ri(x,P)$ $(i=n,n-1,\ldots,2,1)$. This requires project information representing the entire project R&D phase and the number of cycles remaining until project R&D completion. This information is normally based on subjective evaluations and estimates which are used to derive the resource to benefit relationships. Gear, et al. [Ref. 9] analyzed several dynamic programming models similar to and including Hess' model. They observed that this form of the model has the advantage of catering to the multistage learning and decision nature of R&D projects. Although this aspect is referenced throughout the literature, the model forms presented above do not consider it as well as the dynamic programming form.

f. Interactive Programming Models

Winkofsky, et al. [Ref. 7] reviewed several authors that proposed interactive programming models as solution techniques for multiple criteria problems. These models can provide helpful tools in the R&D portfolio selection process. Zoints and Wallenius [Ref. 23] proposed a man-machine interactive programming method which allows a decision maker to optimize an implicit benefit function involving multiple objective or goal functions. The benefit function is a composite objective function and is unknown to the decision maker; however, it is assumed to be a linear function, or in a more general form a concave function, of several known goal functions. The implicit composite objective function is maximized against a set of convex constraints through the decision maker's answers to yes-or-no questions involving trade offs between possible goal function solutions. Zoints and Wallenius' method initially optimizes a computer generated composite objective function including the goal function constraints and an arbitrary set of function multipliers. The technique produces a Pareto-optimal solution to the problem. Next a subset of nonbasic variables is generated that, if introduced into the basis, would continue to yield a Pareto-optimal solution. For these selected variables a series of trade offs are defined which increase or decrease each of the goal functions and the trade offs are presented to the decision maker. The decision maker's responses to the trade offs are used to generate a new set of goal function multipliers. The new multipliers develop a new composite objective function closer to the implicit function. The authors state that successive iterations of this process assures convergence to the optimal solution. Their premise is that all Pareto-optimal solutions form a subset of all extreme point solutions and with each iteration a Pareto-optimal solution is eliminated from the set of possible optimal solutions. Since there is a finite number of extreme points there will be a finite number of iterations required to obtain the optimal solution.

C. DECISION PROCESSES

The majority of models presented in the literature are proposed for or utilized in single level organizations. Several authors have proposed extending these model forms into methodologies or decision processes for use by multilevel organizations. Baker, et al. [Ref. 13] and Winkofsky, et al. [Ref. 12] presented such processes. Both articles concentrated on budget allocation of R&D dollars in a multilevel organization and relied on the interlevel communication and interaction to complete the process. Winkofsky, et al. [Ref. 12] proposed a decision process model in which many subunits within a three level organization are considered. Each unit attempts to minimize the deviations from its 0-1 goal constraints. The lowest level formulates and solves its goal program and provides the resulting solution to the middle level. The middle level formulates a goal program incorporating all subordinate unit program results and additional constraints from the higher level. In turn the higher level solves a composite goal program incorporating middle level results. Conflicts between the levels are resolved either through communication between levels or, if necessary, as directed by higher levels. The process iterates to an optimal solution.

D. ANALYTIC HIERARCHY PROCESS

Saaty [Ref. 24] proposes the "Analytic Hierarchy Process" (AHP) as a decision tool for determining priorities and making trade-offs. Saaty provides many possible applications for this process of which R&D resource allocation is one. Through structuring a hierarchy of criteria stakeholders and outcomes and by developing judgemental based priorities the process contributes in complex problem solving and predictions of likly outcomes. AHP uses three principals of analytic thinking; structuring hierarchies, setting priorities, and logical consistency. AHP enables consideration of a problem as a whole and the study of the component interactions within a hierarchical problem description. Saaty describes an eight step process which encompasses a graphical breakdown of the problem into a decision tree hierarchy, involves pairwise criteria comparisons, establishes decision priorities, and evaluates the consistency of the comparisons. Figure 3.3 shows his example hierarchy structure for choosing R&D projects to ensure adequate future power and electricity. The figure lists six levels of hierarchy, one focus or central objective and the remaining levels each with several elements. The process involves a pairwise comparison starting from the top. A higher level is used as the comparison property for the next lower level. The pairwise comparisons of the elements under a property become the basis for the computation of relative element priorities. Finally, the consistency of the comparisons is investigated.

E. MODEL ACCEPTABILITY AND ANALYSIS

The acceptability of R&D project selection models by industry and government has long been a problem. This is evident from statements in the majority of articles reviewed. Baker [Ref. 6] lists seven limitations of proposed R&D models based on his and others' research. Baker's summary of R&D model limitations is as follows:

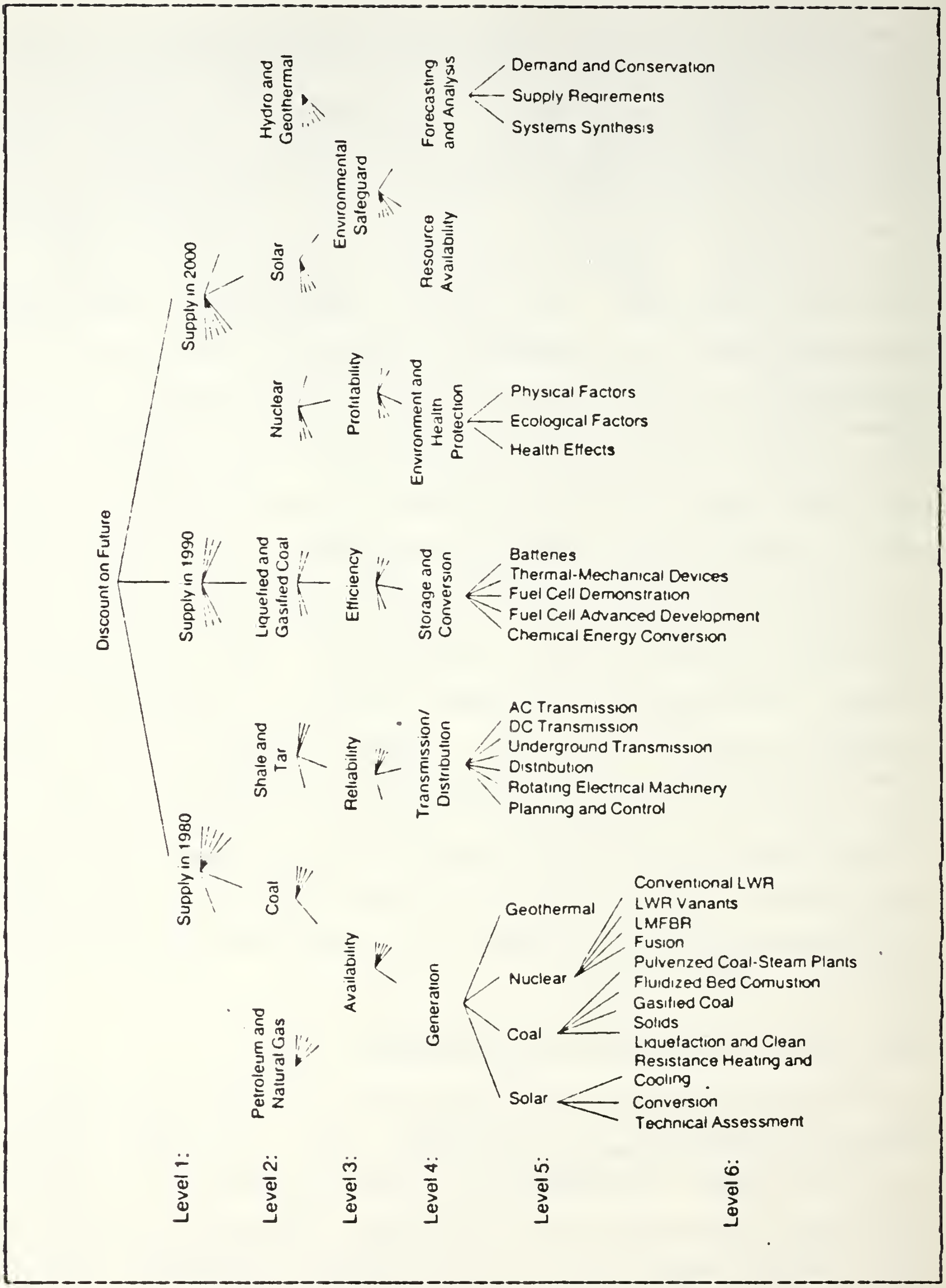


Figure 3.3 R&D Hierarchy Example.

1) Inadequate treatment of project and parameter interrelations with respect to both benefit contribution and to resource utilization.

2) Inadequate treatment of uncertainty as it impacts in benefit measurement and parameter estimation.

3) Inadequate treatment of multiple, interrelated decision criteria which have no underlying measure.

4) Inadequate treatment of the time variant property of the parameters and criteria and the associated problem of continuity in the research program and staff.

5) A restricted view of the problem which (a) portrays a once-a-year investment decision rather than an intermittent stream of investment alternatives, (b) does not include such attributes as timing of the decision, generation of additional alternatives, and recycling, (c) does not recognize the diversity of projects along the spectrum from basic research to engineering, and (d) views the problem as a decision event rather than a hierarchical, diffuse decision process.

6) No explicit recognition and incorporation of the importance of individual R&D personnel.

7) The inability to establish and maintain balance in the R&D program; e.g., balance between basic and applied research, between offensive and defensive research, between breakthrough and improvement orientations, between in-house and contracted projects, between product and process oriented projects and between high risk/high payoff and low risk/moderate payoff projects.

Baker continues with the conclusion that this list of limitations makes it clear why few R&D models have been implemented for use by R&D managers and, in the cases where models are utilized, the majority are the simpler scoring or index form.

Souder [Ref. 17] developed a scoring model to assess the suitability of R&D models. His criteria used for the model, based on his interviews with management scientists and R&D administrators, are presented in Table II. Souder then used his scoring model to rate 26 models for use in R&D project selection decision support. Index and scoring model forms were again found to be in greater use than other model forms.

TABLE II

Five Model Criteria and Their Characteristics

Criteria	Characteristics
REALISM	model includes:
	Multiple Objectives Multiple Constraints Market Risk Parameter Technical Risk Parameter Manpower Limits Parameter Facility Limits Parameter Budget Limits Parameter Premises Uncertainty Parameter
FLEXIBILITY	model applicable to:
	Applied Projects Basic Projects Priority Decisions Termination Decisions Initiation Decisions Budget Allocation Application Project Funding Application
CAPABILITY	models performs:
	Multiple Time Period Analyses Optimization Analyses Simulation Analyses Scheduling Analyses
USE	model is characterized by:
	Familiar Variables Discrete Variables Computer Not Needed Special Persons Not Needed Special Interpretations Not Needed
COST	model has:
	Low Set-up Costs Low Personnel Costs Low Computer Time Low Data Collection Costs

F. SUMMARY

This chapter has reviewed several R&D project selection model forms found through out the literature. The models presented were typical of the literature and were the more general forms which could have application in the following analysis. The commonality observed between model forms is the use of subjective project benefit relationships in some manner. Decision processes and the Analytic Hierarchy Process were briefly presented as methods for approaching the R&D project selection problem. Table III summarizes the models presented in this chapter. Other proposed project selection models are listed in the bibliography. The next chapter describes a R&D program prioritization process proposed within the Marine Corps, and classifies the process model form according to the literature.

TABLE III

Summary of Reviewed Models and References

Author/Reference	Model Form Descriptor Used
Asher (1962) [Ref. 19]	Linear Programming
Augood (1973) [Ref. 8]	Checklists Simple Quantified Profile Indices
Baker (1974) [Ref. 6]	Benefit Measurement Comparative Scoring Benefit Contribution Project Selection/Allocation Ranking Linear Programming Non-linear Programming Dynamic Programming Integer Programming
Chidambaram (1970) [Ref. 20]	Non-linear
Cooper (1981) [Ref. 18]	Empirical (scoring)
Hess (1962) [Ref. 22]	Dynamic Programming
Souder (1973) [Ref. 16]	Profitability Index Linear Non-linear Zero-One
Taylor et al. (1982) [Ref. 21]	Integer Non-linear Goal Programming
Winkofsky et al. (1980) [Ref. 7]	Value Measurement Checklist Scoring Economic Index Portfolio Selection Linear Programming Integer Programming Nonlinear Programming Interactive Programming
Winkofsky et al. (1981) [Ref. 12]	0-1 Goal Programming
Zoints et al. (1976) [Ref. 23]	Interactive Programming

IV. MCDEC PRIORITIZATION PROCESS

A. INTRODUCTION

The MCDEC Prioritization Process consists of four time-dependent phases synchronized with the Marine Corps participation in the DOD Planning Programming and Budgeting System and is organized for implementation at the Marine Corps Development Center (DevCtr), MCDEC. Figure 4.1 depicts this synchronization and the process timetable for a single cycle. The four phases include determining deficiencies and requirements, prioritizing deficiencies and requirements, prioritizing research and development programs, and completion of funding profiles. This process, as described by Major J. L. Creed, USMC, in "A Guide for the Performance of the Development of the MCDEC R&D Program Prioritization Process, Methodology Manual" [Ref. 25], is carried out under the responsibility of the Office of the Deputy Chief of Staff (DC/S), Developmental Coordination (DC), DevCtr, MCDEC, and by two primary groups, the Prioritization Working Group (PRWG) and the Chief of Staff's (C/S's), DevCtr Prioritization Committee (Pri Com). Each Division and Directorate of the DevCtr provides a representative for membership in the PRWG. The Division and Directorate Heads compose the C/S's DevCtr Prioritization Committee. Appendix A details the phases and tasks of the process and lists the DevCtr Divisions, Directorates, and Developmental Coordination Branches responsible for completing each step. This chapter describes the process concepts and concentrates on the participants as shown in Figure 4.2 .

TIME	MCDEC Process		HQMC RDT&E POM
JAN FEB	Phase I Plans Update	Survey Analysis	Previous Cycle
MAR APR	MAA Update		
MAY JUN JUL	Phase II Prioritize MAA Deficiencies		
AUG SEP OCT	Phase III Prioritize R&D Programs		Preliminary Program Development
NOV DEC	Phase IV Funding Profiles		
JAN FEB	Following Cycle		C/S USMC Committee and POM Working Group
MAR APR			
MAY JUN JUL			Negotiations and Budget
AUG SEP			

Figure 4.1 MCDEC Process and RDT&E POM Cycle.

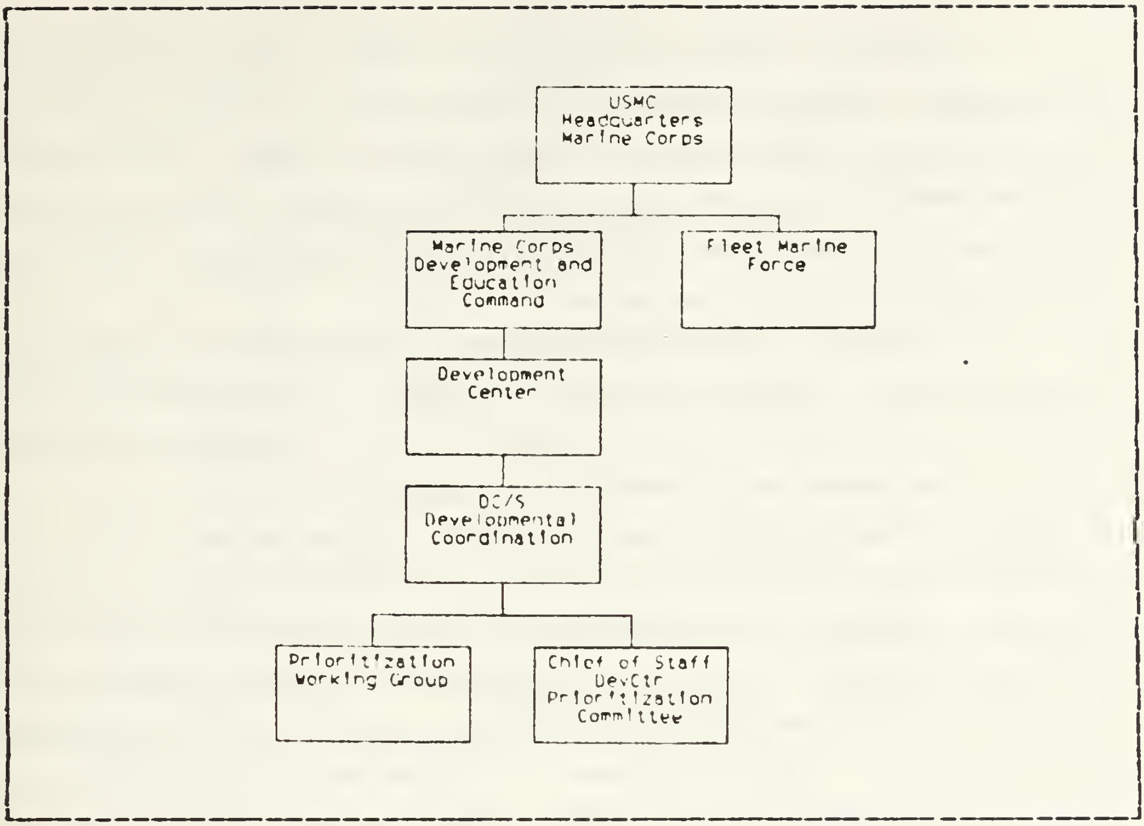

USMC
Headquarters
Marine Corps
Marine Corps Development and Education Command
Fleet Marine Force
Development Center
DC/S Developmental Coordination
Prioritization Working Group
Chief of Staff DevCtr Prioritization Committee

Figure 4.2 MCDEC Process Participants.

B. PROCESS PHASES

1. Phase I

The determination of deficiencies and requirements, phase I, involves three general tasks and serves to provide the PRWG with an information base for the following subjective evaluations. First, the Marine Corps Midrange Objectives Plan (MMROP) and the Marine Corps Long Range Plan (MLRP) are updated utilizing Defense Guidance (DG), the FYDP, previous POM recommendations, and other appropriate research and development information.

Second, Fleet Marine Force (FMF) input is solicited by survey analysis through questionnaires, opinionnaires, and personal interviews. This task provides the eventual system users with an opportunity to input observations of mission deficiencies, ideas for new programs, and their rankings of ongoing programs.

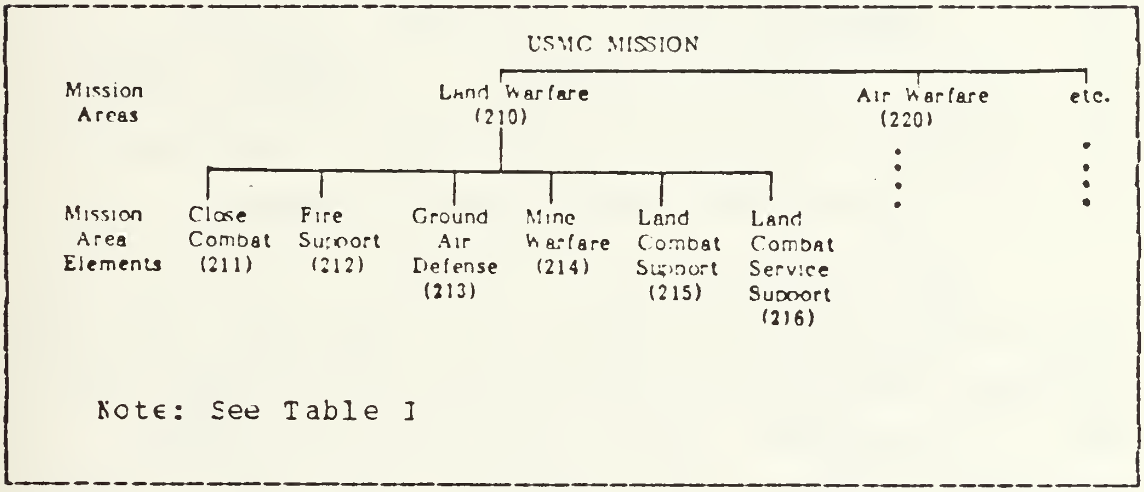
Finally, MAAs are conducted which provide the framework necessary for phase II and serve to formalize all deficiencies that diminish the capability to perform the mission area. The MAAs are classified according to the Mission Area Elements (MAEs) listed in Table I, and performed by project officers under the direction of the Planning and Evaluation Branch, DevCtr. The assigned project officer conducts his analysis through a series of mission categorizations which are based on the previously updated plans and other established Marine Corps Doctrine. Three basic categorizations occur during the MAA. First, the mission area element is defined into its general and specific operational mission, then the resources necessary to accomplish the operational missions are identified, and finally each resource is analyzed against each operational mission to identify if any deficiencies exist. The collection of these identified mission deficiencies present the recommended corrective actions to obtain full Marine Corps capability in a mission area.

2. Phase II

Phase II merges the identified mission element deficiencies into a single prioritized list. To accomplish this ranking, the PRWG first receives briefings concerning the MAAs and survey analyses from phase I. Next, the PRWG constructs a decision tree based on the presented information to order deficiencies within mission area elements. The tree development is represented by Figures 4.3 through

4.6. This development parallels the mission element categorization process conducted during the MAAs and applies multi-attribute utility analysis to the categories as explained by Creed [Ref. 25]. The subsequent evaluations of the elements and missions, represented by the decision tree branchs, also rely heavily on the MAAs as presented to the PRWG by the project officers, and by the Planning and Evaluation Branch. Additional technical assistance for the decision tree construction and analysis is provided by the Analysis Support Branch.

The decision tree is based in the USMC mission areas and elements listed in Table I and is represented in Figure 4.3. The tree branches through the doctrine based general and specific missions for each element (see Figure 4.4), and then these specific missions are shown supported by the necessary resources, as presented in Figure 4.5.



Note: See Table I

Figure 4.3 Decision Tree, Established Base.

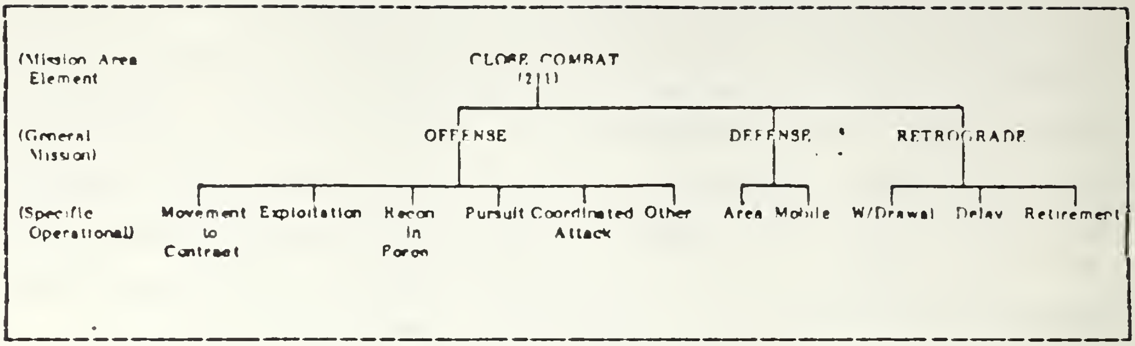


Figure 4.4 Decision Tree, General and Specific Missions.

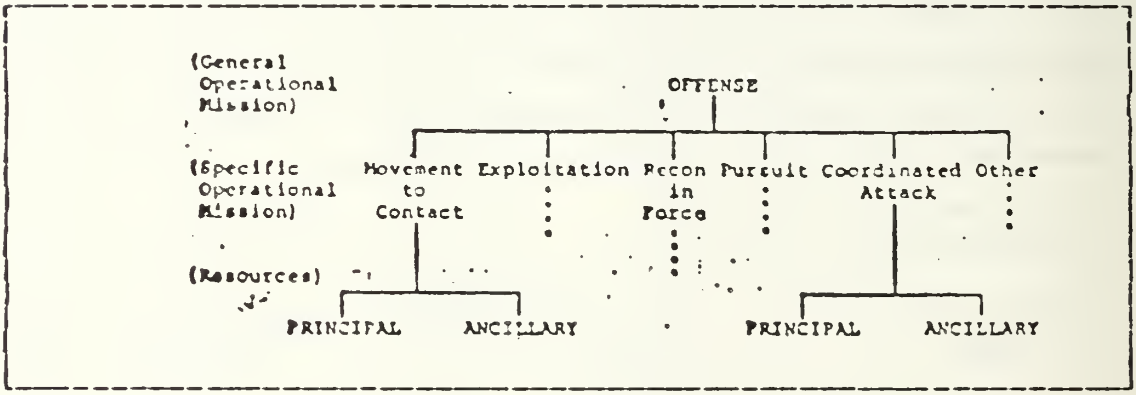


Figure 4.5 Decision Tree, Resources.

The resources shown in Figure 4.5 are further defined into principal and ancillary categories. Principal resoures correspond to equipment or weapon systems that are used to accomplish the specific mission directly, and ancillary resources are necessary but only indirectly support the mission. A common list of resources necessary to accomplish the specific operational mission is initially applied to all specific operational missions with some resources subsequently being determined not applicable for all missions. As an example, Creed [Ref. 25] suggests a possible resource list for the close combat mission area

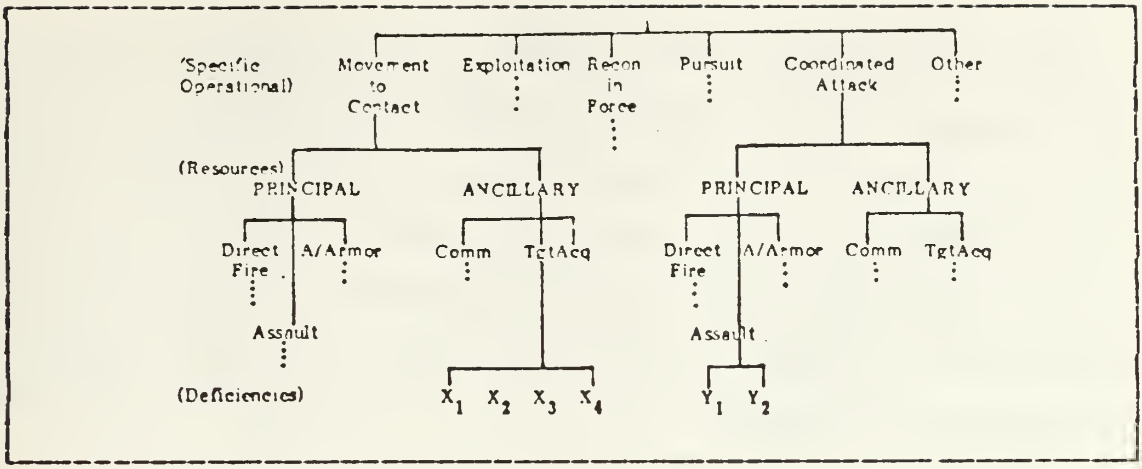


Figure 4.6 Decision Tree, Deficiencies.

element to be direct fire, assault, and anti-armor weapons for the principal resource category and communication equipment and target acquisition devices for the ancillary resources. The resource deficiencies and, thus, the mission deficiencies shown in Figure 4.6 are identified by evaluating each resource as it supports the accomplishment of the specific operational mission.

The PRWG assigns subjective importance values[3] (0.01 to 1.00), to each branch of the decision tree from the mission area through the deficiency level. These values are based on presented information and finalized through collective group judgement. The Mission Area Values (MAV) represent the relative importance of each mission area within the USMC mission and the Mission Area Element Values (MAEV) represent the relative importance of each mission area element within the mission area. Similarly, General Operational Mission Values (GOMV), Specific Operational Mission Values (SOMV), and Deficiency Values (DV) represent the relative importance of each general operational mission within the mission area element, each specific operational mission within the general operational mission, and each deficiency within the specific operational mission respectively. The initial value sets, MAEV, GOMV, SOMV, and DV, are normalized to a common base for each set which allow comparisons across all elements, missions, and deficiencies in their respective decision tree level. The Deficiency Relative Importance Weight (DRIW) for each specific mission deficiency is defined as

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[3] These values represent linear relative importance, (ie, a .74 deficiency is twice as critical as a .37 deficiency).

$$DRIW = MAV \bullet MAEV \bullet GOMV \bullet SOMV \bullet DV \qquad (4.1)$$

where,

MAV = Mission Area Value,
MAEV = Mission Area Element Value,
GOMV = General Operational Mission Values,
SOMV = Specific Operational Mission Values, and
DV = Deficiency Value.

The DRIWs, in turn, determine a mission deficiency rank ordering.

3. Phase III

Phase III prioritizes ongoing RDT&E acquisition programs through presentation of the prioritization group and committee with available information, assigning program subjective values, deriving program effectiveness, combining previous program prioritizations, and presenting the results for Director, DevCtr approval. First, the Prioritization Working Group receives briefs by the Developmental Project Officers (DPOs) to assist in determining the worth and utility of the program. Next, survey analysis briefings provide the FMF evaluations of current RDT&E programs. This information presented in the PRWG briefs is also provided separately to the DC/S DC Prioritization Committee.

The next task of phase III is the subjective prioritization of RDT&E programs. During this task, a sample of experts are solicited for their desired RDT&E program rank orderings and relative worth values (0.01 to 1.00). This opinion sample consists of the DC/S DC Prioritization Committee membership, minimally, and may include other qualified individuals. The prioritization is performed using an analytic Delphi process where the independent rank ordering and worth values are combined and returned to the sample membership for study and resubmission. After at least three replications with relatively common consecutive listings, the prioritization concludes with a program ranking and program Subjective Evaluation Values (SEVs).

Following the subjective evaluation the RDT&E programs are prioritized based on their mission deficiency effectiveness. The PBWG identifies all deficiencies within each mission element that are directly affected by a RDT&E program, and it evaluates the proportion at which the program accomplishes the specific deficiency. This proportion is defined as the Program's Proportion of Deficiency Accomplishment (PPDA). The evaluation process relies heavily on the input from the DPOs concerning each program's proposed operational characteristics. The product of the specific DRIW, assigned in phase II, and the specific PPDA are summed, over all deficiencies, to obtain a program Deficiency-Derived Efficiency Value (DDEV) as

$$\text{DDEV} = \text{Sum/d} \; [\; (\text{DRIW}) \bullet (\text{PPDA}) \;] \tag{4.2}$$

where,

Sum/d = Summation over all deficiencies,
DRIW = Deficiency Relative Importance Weight and
PPDA = Program's Proportion of Deficiency Accomplishment.

The programs are then ranked according to the DDEV values.

The PRWG obtains a final RDT&E program ranking by combining the subjective and deficiency-derived prioritizations. A Subjective Evaluation List Weight (SELW) and a Deficiency-Derived List Weight (DDLW) is assigned to the appropriate program list combining them in a linear relationship based on PRWG consensus of each list's validity. The sum, by program, of the weighted prioritized lists provides the Final RDT&E Program Value (FPV) as

$$FPV = (SELW) \bullet (SEV) + (DDLW) \bullet (DDEV) \qquad (4.3)$$

where,

SELW = Subjective Evaluation List Weight,
SEV = Subjective Evaluation Value,
DDLW = Deficiency-Derived List Weight, and
DDEV = Deficiency-Derived Efficiency Value.

The final prioritized ranking is accomplished according to the FPV and this completes phase III.

4. Phase IV

Phase IV completes the annual process by summarizing the three preceding phases and proposing funding profiles which reflect the prioritized program ordering. The process summary is used as a turnover file for the next prioritization cycle and the funding profiles are submitted to HQMC for utilization in the RDT&E PCM development process. Creed [Ref. 25] suggested further development in this phase which has not yet taken place. Currently, these funding profiles are developed based on solely the judgement of the tasked DevCtr branch using no mathematical optimization or algorithms.

C. FORM OF MODEL IN MCDEC PROCESS

Throughout the literature, as reviewed in the previous chapter, and in the following analysis the form of a budget allocation and program selection model is important. The MCDEC model as described is a benefit measurement, scoring model. As with typical models of this type, the MCDEC model combines various attributes into a single value. Within this model form classification differences in subjective benefit weight assignment schemes are observed. These differences range between weight assignment by a single manager to assignment based on a multivariable regression of subjective program evaluations from many solicited sources. The MCDEC process attempts to base its benefit weight assignment on many inputs from operational and non-operational forces as well as agencies outside of the Marine Corps. The inputs are combined into benefit weights through a group consensus procedure. In general the MCDEC prioritization process is similar to R&D project selection models proposed in the literature and is classified with the majority of implemented models in industry.

D. SUMMARY

This chapter has presented the MCDEC prioritization process as described by Creed [Ref. 25] and by information obtained through liaison with the process developing agency, the Analysis Support Branch, DC/S DC, DevCtr. The process emphasizes synchronization with the Marine Corps participation in the DoD PPBS, and utilization of R&D program evaluation input from many organizational levels. The process requires several subjective evaluations concerning the R&D programs and mission deficiencies which are then combined into a basis for R&D program ranking. Table IV summarizes the subjective parameters necessary for the process. The chapter concludes with classifying the model form used in the MCDEC process as a benefit measurement scoring model, according to similarities with proposed models in the literature.The literature suggests other model form applications, model limitations, and model evaluation criteria which will assist further investigation of possible improved alternatives or enhancements to the MCDEC prioritization process.

TABLE IV

Subjective Model Parameters

PHASE	TASK	PARAMETER	ASSIGNMENT	RANGE
II	3	MAV	PRWG	0.01-1.00
II	3	MAEV	PRWG	0.01-1.00
II	3	GOMV	PRWG	0.01-1.00
II	3	SOMV	PRWG	0.01-1.00
II	3	DV	PRWG	0.01-1.00
III	3	SEV	Pri Com	0.01-1.00
III	4	PPDA	PRWG	0.01-1.00
III	5	SEIW	PRWG	NS
III	5	DDIW	PRWG	NS

NS = Not Specified
Tasks are detailed in Appendix A

V. A MCDEC PORTFOLIO SELECTION MODEL

A. INTRODUCTION

The MCDEC process presented in the previous chapter was identified as a benefit measurement scoring model with similar characteristics as models currently used in industry. The literature also proposes portfolio selection models which use benefit measurement relationships to optimize resource allocation through various mathematical programming techniques. The MCDEC process, as proposed, does not attempt to optimize program resource allocation and, thus, the obvious first process improvement to be investigated is the extension of the current model into a portfolio selection model. The simplest and most comprehendable way This can be accomplished is by formulating the process as a linear programming model. This model form approximates resource and benefit relationships with straightforward linear functions that are easly understood. The linear programming model is the basic structure for other more complicated portfolio selection models and will provide a base for observing advantages from a process model change. The primary purpose of the following linear program development is to illustrate the feasibility, flexibility, and required assumptions of a portfolio selection model as applied to the MCDEC prioritization process and does not include all constraints and relationships required for a complete RDT&E funding allocation.

B. FORMULATION

The initial step of any linear programming formulation can be viewed as a thought exercise. In this exercise the linear program is viewed as a black box which provides an output when given the necessary data. The thought exercise defines the desired output and the remaining formulation structures the linear program to obtain this output. The currently proposed MCDEC process output provides a prioritized program listing based on relative program importance in accomplishing mission deficiencies. A linear programming output which represents the proportion of a program that is selected or funded provides program prioritization and, additionally, resource allocation information.

The next formulation step is to define index nomenclature for the element categories under consideration in the linear program. The MCDEC process concentrated on two elements, mission deficiencies and RDT&E programs. These two are also used in the following linear programming model formulations. The indexing letter i will represent a program and the letter j will represent a mission deficiency. Also, when considering a resource allocation process several time periods are normally necessary. The letter k will be used to index a time period in the formulation. The total number of programs, deficiencies, and time periods will be represented by the letters p, d, and t respectively. In the following discussion the series summation of any indexed values will be denoted as Sum/index [indexed values] such as Sum/i[Xi], which represents the summation of the values Xi over i = 1...p, where p is the total number of programs under consideration.

The benefit measurement output data provided by the MCDEC process is defined in the previous chapter and is used here for the linear program formulation. Four value sets of interest are developed in the MCDEC process. The Deficiency Relative Importance Weight (DRIW) is established in phase II. In phase III the Prioritization Working Group develops the Program's Proportion of Deficiency Accomplishment

(PPDA), and the Subjective Evaluation Value (SEV). These three values are combined in equations 4.2 and 4.3 to provide the Final RDT&E Program Value (FPV). Resource data is not defined in the current process but is considered during Project Development Officer briefs to the prioritization group and committee. The resource data is also used in phase IV to provide suggested RDT&E,Navy POM input. Previous POMs that are independent of the process are used as proxy resource estimators for illustration in the following formulations.

The decision variables for the formulations are implied from the desired output. The following series of linear programs will be formulated using the decision variable Xi which represents the proportion of the ith program that is funded or Xik which represents the proportion of the ith program that is funded in the kth time period. The values Xi and Xik are defined between and including zero and one. A variable, Yi, which represents the proportional deviation from a fixed jth deficiency accomplishment goal is used in later linear programming formulations and is also defined between and including zero and one.

As in the literature, the objective functions for the following formulations are provided from the benefit measurement model. For the initial linear program formulation the Final Program Value (FPV) vector from the MCDEC process is used. This vector represents a combination of deficiency derived and subjectively assigned mission deficiency accomplishment program values. The vector FPV contains a value FPVi for each program, where i is an integer from 1 to p. Formulation 5.1 provides an initial unconstrained linear programming model that is equivalent to the MCDEC benefit measurement model and can be solved by observation. This linear program maximizes the total relative program importance as individually defined by each FPVi, reduced by the available program funding proportion Xi, and summed over all programs. The optimal solution for this formulation is obtained when Xi is set at one for all i. The initial formulation is

$$\text{maximize} \qquad \text{Sum/i} \ [(\text{FPVi})(\text{Xi})] \qquad (5.1)$$

$$\text{subject to:} \qquad 0 \le \text{Xi} \le 1$$
$$i = 1 \ldots p.$$

Formulation 5.1 may be trivial but it provides a linear program structure equivalent to the MCDEC process which can be constrained by budget or deficiency relationships. Formulation 5.2 provides a constrained version of formulation 5.1 as

$$\text{maximize} \qquad \text{Sum/i} \ [(\text{FPVi})(\text{Xi})] \qquad (5.2)$$

$$\text{subject to}$$

$$\text{Sum/i} \ [(\text{Aki})(\text{Xi})] \le \text{Bk}$$
$$0 \le \text{Xi} \le 1$$
$$i = 1 \ldots p$$
$$k = 1 \ldots t$$

where,

FPVi = ith final program value,
Xi = proportion of ith program funded,
Bk = available budget resource in time period k,
Aki = full funding level of ith program in time period k,
p = number of programs, and
t = number of time periods.

If Bk is greater than or equal to Aki, summed over all programs for each time period, the optimal solution to formulation 5.2 is also at Xi equal one for all i. This formulation, however, will provide a tool to observe the optimal allocation change when the budget level Bk is reduced, thus constraining the objective function. The new optimal program priority listing will not necessarily be the same as the ordering provided by FPV. After the linear program computations, the vector (FPV)(X) represents the proportional reduction in the programs' Final Program Value and provides the revised priority listing under budget constraints.

Formulation 5.2 is illustrated by an example. Table V lists the benefit measurement output values from four RDT&E programs considered during a partial MCDEC process test conducted by the Development Center. The respective budget allocation data from the RDT&E POM is also listed. A constant is imbedded into the linear program formulation which defines possible budget reductions and thus a tighting of the constraints. The constant is added by replacing the budget constraints of formulation 5.2 with

$$\text{Sum/i}\,[\,(Aki)(Xi)\,] + BR(Bk) \leq Bk \qquad (5.3)$$

where,

BR = budget reduction proportion.

Eight progressivly reduced budget conditions are used in this example.

Table VI lists the resulting optimal solutions and rankings for each of the eight budget conditions. The proportion of full funding for each project changes but not as the MCDEC prioritizing vector FPV implies. Although the FPV of program C0020 is larger than the FPV for both programs C0021 and C0082, the latter two programs are fully funded at each budget reduction. The values of FPV alone would not suggest

TABLE V

MCDEC Portfolio Selection Model Example Data

Program	FPV	Budget Data yr 1	yr 2	yr 3	yr 4	yr 5
C1120	7.32464	4747	20874	9176	8987	8988
C0020	6.9616	21100	22200	30100	33700	70500
C0021	4.79723	4172	4297	4369	4268	3927
C0082	4.21985	361	370	380	442	443
Budget Sum =Bk=		30380	47741	44025	47397	83858

these funding reductions. For this example, observation of the differences in the programs' budget profiles as listed in Table V would imply that the optimal funding in a budget constrained problem would be obtained by reducing the most expensive program first. However, in a larger example the optimal solution may not be as evident.

Formulation 5.2 can be expanded to include a time index for the funding proportion variable X. This expansion is formulated as

$$\text{maximize} \quad \text{Sum}/k\ [\ \text{Sum}/i\ (FPVi)(Xik)\ ] \qquad (5.4)$$

subject to

$$\text{Sum}/i\ [\ (Aki)(Xik)\ ] + BR(Bk) \leq Bk$$

$$0 \leq Xik \leq 1$$

$$i = 1 \ldots p$$

$$k = 1 \ldots t$$

where,

BR = budget reduction proportion, and

Xik = proportion of ith program funded in the kth period.

The data values for FPVi, Aik, and Bk remain the same as in formulation 5.2. Formulation 5.4 provides greater flexibility in funding level possibilities and provides a sequence of program rankings for each subsequent year. Table VII provides a summary of the funding proportion solutions and the ranking according to the vector (FPV)(X) for each year and budget condition. The most expensive program C0020 is again the only program that requires less than full funding except in the most extreme condition where program C1172 is also less. Observing the proportional funding profile of program C0020 implies that the first time period is the most restrictive in each budget condition. Considering funding levels in each time period allows a greater utilization of resources available in the less restrictive periods.

TABLE VI

Formulation 5.2 Solution Results

	Proportion of Full Budget							
	1.0	.99	.95	.90	.85	.80	.75	.50
Vector X								
C1120 X1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	.92
C0020 X2	1.0	.979	.892	.784	.677	.57	.462	0.0
C0021 X3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
C0082 X4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BR	.00	.01	.05	.10	.15	.20	.25	.50
Ranking								
C1120	1	1	1	1	1	1	1	1
C0020	2	2	2	2	3	4	4	4
C0021	3	3	3	3	2	2	2	2
C0082	4	4	4	4	4	3	3	3

Notes

1. X = Proportion of program funded and is specific for each budget reduction case.
2. BR = Proportion of budget reduction.
3. Ranking is according to the vector (FPV)(X).

TABLE VII

Formulation 5.4 Solution Results

	Proportion of Full Budget							
	1.0	.99	.95	.90	.85	.80	.75	.50
	Xik Matrix							
C1120 yr 1-5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	.92[1]
C0020 yr 1	1.0	.979	.892	.784	.677	.57	.462	0.0
2	1.0	.985	.927	.854	.780	.707	.634	.269
3	1.0	.986	.93	.859	.789	.719	.648	.298
4	1.0	.988	.94	.881	.821	.762	.702	.405
5	1.0	.986	.928	.856	.784	.712	.640	.280
C0021 yr 1-5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
C0082 yr 1-5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BR	.00	.01	.05	.10	.15	.20	.25	.50
Ranking								
C1120	1	1	1	1	1	1	1	1
C0020	2	2	2	2	2	2	3	4
C0021	3	3	3	3	3	3	2	2
C0082	4	4	4	4	4	4	4	3

Notes
1. C1120 is funded at .92 for year one only and at 1.0 for the years two through five.
2. Xik = Proportion of program funded and is specific for each year and budget reduction case.
3. BR = Proportion of budget reduction.
4. Ranking is according to the vector (FPV) (Sum/yr (X)).

The Final Program Value (FPV) provided by the MCDEC process as a benefit measurement is postulated to represent the relative program importance in accomplishing mission deficiencies. The primary purpose of defense systems acquisition and Marine Corps RDT&E as presented previously in Chapter II, is the accomplishment or alleviation of mission deficiencies. Concentration on a portfolio selection model which considers only the FPV and budget constraints may not produce solutions representing the greatest accomplishment of individual mission deficiencies. The next two proposed formulations consider mission deficiency accomplishment in terms of other MCDEC output values under separate constraining conditions. A third additional formulation concentrates directly on the number of deficiencies alleviated.

Formulation 5.5 optimizes at a level in the MCDEC benefit measurement model where each deficiency is considered individually. The FPV is constructed from the previously presented values of SEV and DDEV. The DDEV directly considers each deficiency where the SEV is the subjective evaluation of the RDT&E programs only. Equation 4.2 defines the vector DDEV as the product of the Deficiency Relative Importance Weight (DRIW) and the Program Proportion of Deficiency Accomplishment (PPDA) summed over all deficiencies. Letting the vector PPDA be linearly reduced by the funding proportion of the respective program provides a means to optimize the mission deficiency accomplishment directly. The linear program to maximize the RDT&E program's DDEV is formulated as

$$\text{maximize} \quad \text{Sum}/i\,[(DDEV_i)(X_i)] \qquad (5.5)$$

or equivalently,

$$\text{maximize} \quad \text{Sum}/i\,[\text{Sum}/j\,[(DRIW_j)(PPDA_{ji})(X_i)]]$$

$$\text{subject to}$$

$$\begin{gathered} \text{Sum}/i\,[(A_{ki})(X_i)] + ER(B_k) \le B_k \\ 0 \le X_i \le 1 \\ i = 1 \ldots p \\ j = 1 \ldots d \\ k = 1 \ldots t \end{gathered}$$

where,

d = number of deficiencies,

DDEVi = ith program's deficiency derived effectiveness,
DRIWj = jth deficiency relative importance weight, and
PPDAji = ith program's accomplishment of jth deficiency.

Additional constraints concerning individual mission deficiencies which establish lower bounds on the deficiency's accomplishment level may be included in formulation 5.5. These lower bounds, however, introduce the possibility of no feasible linear programming solutions existing because the lower bounds are set too high. Adding a new variable, Yj, which represents the deviation from accomplishing the lower bound alleviates this possibility. With the variable Yj included the lower bound becomes a deficiency accomplishment goal. Including the additional deficiency accomplishment constraints the formulation becomes

$$\text{maximize}\quad \text{Sum/i}\,[\,\text{Sum/j}\,[\,(DRIWj)(PPDAji)(Xi)\,]\,] \qquad (5.6)$$

$$\text{subject to}$$

$$\begin{gathered}
\text{Sum/i}\,[\,(Aki)(Xi)\,] + BR(Bk) \le Bk \\
\text{Sum/i}\,[\,(PPDAji)(Xi)\,] + (Yj)(DAj) \ge DAj \\
0 \le Xi \le 1 \\
0 \le Yi \le 1 \\
i = 1 \ldots p \\
j = 1 \ldots d \\
k = 1 \ldots t
\end{gathered}$$

where,

DAj = jth deficiency's accomplishment level, and
Yj = deviation from DAj achieved.

The solution to formulation 5.6 will provide program selection, prioritization, and deficiency accomplishment information. Program selection criteria can be defined according to the funding level. If the ith RDT&E program's funding level, Xi, is zero it follows that the ith RDT&E program should not be selected under the constraints established in the linear program. RDT&E programs that have low proportional funding levels, Xi, serve to identify RDT&E programs that may need to be reevaluated according to their economical accomplishment of mission deficiencies prior to continued investment.

To prioritize the RDT&E programs, two possibilities follow from the present MCDEC process and formulation 5.6. The possible prioritization vectors are

$$[(DDEV)(X)] \tag{5.7}$$

or,

$$(X)[(DDLW)(DDEV)+(SELW)(SEV)] = (X)(FPV) \tag{5.8}$$

where,

SELW = subjective evaluation list weight,
SEV = subjective evaluation value,
DDLW = deficiency-derived list weight,
DDEV = deficiency-derived efficiency value,
FPV = final program value, and
X = program proportion funded.

Equations 5.7 and 5.8 represent vectors that could be used depending on the importance given to the vector SEV. The listings weights represented by SELW and DDLW are assigned by the Prioritization Working Group (PRWG) to compute the FPV in phase III of the MCDEC process. If full funding is available, ranking programs by equation 5.8 is equivalent to the current MCDEC prioritization process.

Formulation 5.6 also provides a proportion of deficiency accomplished according to the value

Sum/i [(PPDAji)(Xi)]. (5.9)

This information would be valuable to a decision maker for identifying deficiencies that are not fully accomplished. The additional variable, Yj, provides similar identification information concerning deficiencies not achieving their minimum accomplishment levels as set by the constant DAj.

To further illustrate the linear programming model formulations presented in this section a larger set of Development Center-produced MCDEC process test data is used. The data involve 158 mission deficiencies and 74 RDT&E programs. The proxy budget data is obtained by using the same year RDT&E,Navy POM.

Table VIII shows the results of this larger data set when subjected to formulation 5.2. The table lists six columns. The first two columns from the left name and describe the budget conditions used. The next three list the number of RDT&E programs fully, partially, or not funded respectively. The last column provides the number of changes to the original program prioritization list when using formulation 5.2. The results depict the RDT&E program selection produced by the linear programming model solution for maximizing the Final Program Value (FPV) subject to five progressively restrictive budget cases. As should be expected, fewer programs are funded fully as budget reductions are imposed. However, if the FPV prioritization listing is used to select the funded programs, the optimal selection obtained through the linear program may not be produced. The right hand column of Table VIII provides the number of programs whos priority position is lowered from the constrained case. This column contains the number of programs which lost their priority position because (FPVi)(Xi) < (FPVb)(Xb), where i represents the program under consideration and b represents the program initially ranked immediatly below the ith program. These numbers are an indication of the the differences in selecting RDT&E programs by a linear programming solution rather than the initial prioritized list produced in the MCDEC process.

TABLE VIII

Results of Formulation 5.2 with MCDEC Data

Case	BR	Program Funding Full	Part	None	Priority Changes in FPV Ranking
A	0.00	74	0	0	0
B	0.10	72	1	1	2
C	0.15	71	1	2	2
D	0.25	69	2	3	5
E	0.50	61	2	11	13

The results of formulation 5.5 with the set of MCDEC process data is shown in Table IX. These results depict the linear program solution for maximizing the program's Deficiency-Derived Efficiency Value (DDEV) when subjected to progressively restricted budget constraints. The noticeable solution difference between maximizing DDEV instead of FPV is the larger quantity of RDT&E programs dropped during the DDEV budget reduction conditions. The differences between the two formulation results is due to the lack of the Subjective Evaluation Value (SEV) in the DDEV solution. Assuming that the DDEV is a more direct and objective measure of RDT&E program accomplishment of mission deficiencies then in an actual application the partially funded and non-funded programs would be identified for further evaluation prior to selection. The right hand column of Table IX provides the number of programs whose priority position lowered when comparing a ranking of (Xi)(DDEVi) to a ranking according to the vector DDEV only.

TABLE IX

Results of Formulation 5.5 with MCDEC Data

Case	BR	Program Funding Full	Part	None	Priority Changes in DDEV Ranking
A	0.00	74	0	0	0
B	0.10	71	1	2	3
C	0.15	69	1	4	4
D	0.25	60	1	13	13
E	0.50	50	2	22	23

Formulation 5.6 further restricted the maximization of Sum/i [(DDEVi)(Xi)] by including constraints for each mission deficiency in addition to the budget constraints. Table X provides formulation 5.6 results when using the same MCDEC data. In this illustration the jth Deficiency Accomplishment (DAj) value is set equal to a single quantity for all deficiencies. This value for DA represents a deficiency accomplishment goal which the model user would like the portfolio of selected RDT&E programs to achieve. As previously stated, this goal may not be feasible with currently considered programs. The variable Yj in formulation 5.6 provides assurance that a feasible solution will be obtained, and it provides identification of the deficiencies that fail to meet the user's goal. If Yj is equal to zero

then the jth deficiency goal, DAj, has been met. If the Yj value is one then no accomplishment of the jth deficiency is provided under the specified set of constraints. The results of four cases are shown in Table X. Four values of DA are used and each DA case is further subjected to five budget reduction conditions. For each case shown in Table X the budget reductions impose the same RDT&E program selection portfolio as in formulation 5.5. The two priority change columns provide the number of programs that lower their priority standing as a result of the linear programming model reducing the funding proportion Xi to obtain an optimal solution.

The deficiency accomplishment columns, of Table X, show the number of deficiencies that obtain the goal of DA in each case and the numbers of deficiencies partially and not accomplished. In the fully funded cases all RDT&E programs are selected as in the current MCDEC process and all deficiencies are at least partially accomplished. Case I-A shows that 74 deficiencies are greater than or equal to 100 percent accomplished and 84 deficiencies are less than 100 percent alleviated. Case IV-D shows that at a 25 percent budget reduction 87 deficiencies are accomplished at greater than or equal to 85 percent while 63 deficiencies are less than 85 percent alleviated and eight deficiencies are not accomplished. For this data set, these results imply that even when all programs are fully funded many deficiencies are not accomplished at the set goal while others are using resources in excess of that required to meet the goal. For the data used in this illustration 25 deficiencies were accomplished at 200 percent or greater and the largest overaccomplishment was 535 percent. Numbers representing deficiencies move from the DA column to partial and not accomplished columns as budget reductions were imposed that reduce funding for programs that support the specific

TABLE X

Results of Formulation 5.6 with MCDEC Data

Case			Program Funding			Priority Changes		Deficiency Accomplishment		
	DA	ER	Full	Part	None	DDEV	FPV	DA	Part	None
Case I										
A	1.0	.00	74	0	0	0	0	74	84	0
B		.10	71	1	2	3	3	74	83	1
C		.15	69	1	4	4	5	73	84	1
D		.25	60	1	13	13	14	70	83	8
E		.50	50	2	22	23	24	61	87	10
Case II										
A	.95	.00	74	0	0	0	0	77	81	0
B		.10	71	1	2	3	3	77	80	1
C		.15	69	1	4	4	5	76	82	1
D		.25	60	1	13	13	14	73	77	8
E		.50	50	2	22	23	24	64	84	10
Case III										
A	.90	.00	74	0	0	0	0	89	69	0
B		.10	71	1	2	3	3	88	69	1
C		.15	69	1	4	4	5	87	70	1
D		.25	60	1	13	13	14	83	67	8
E		.50	50	2	22	23	24	76	72	10
Case IV										
A	.85	.00	74	0	0	0	0	93	65	0
B		.10	71	1	2	3	3	92	65	1
C		.15	69	1	4	4	5	91	66	1
D		.25	60	1	13	13	14	87	63	8
E		.50	50	2	22	23	24	80	68	10

deficiency. In all DA goal cases, one mission deficiency was not accomplished at any percent when a budget reduction of .10 or .15 was imposed. When the more extreme budget reductions were imposed more programs were not funded and more deficiencies were not accomplished. The linear programming solution procedure concentrates resources into programs that accomplish deficiencies with the highest Deficiency Relative Importance Weight (DRIW) and does not prevent over accomplishment in excess of 100 percent. This allows an optimal formulation to occur with a portfolio that does not select RDT&E programs that only accomplish deficiencies with a low

DRIW. As shown in case I-E, 61 deficiencies were accomplished at or greater than 100 percent while 10 deficiencies were not accomplished. At some point nonaccomplishment of the less important deficiencies will outweigh the benefit from overaccomplishment of the more important deficiencies.

The final linear programing formulation proposed here does not duplicate the MCDEC process in any obvious way but concentrates on maximizing the quantity of all deficiencies accomplished. The following formulation uses the previously defined variable Yj as the deviation from the set deficiency accomplishment goal. The formulation for a goal of 100 percent follows as

$$\text{minimize} \quad \text{Sum}/j\,[Yj] \qquad (5.10)$$

subject to

$$\begin{aligned} &\text{Sum}/i\,[(Aki)(Xi)] + ER(Bk) \leq Bk \\ &\text{Sum}/i\,[(PPDAji)(Xi)] + Yj \geq 1.00 \\ &0 \leq Xi \leq 1 \\ &0 \leq Yi \leq 1 \\ &i = 1 \ldots p \\ &j = 1 \ldots d \\ &k = 1 \ldots t. \end{aligned}$$

Formulation 5.10 optimizes deficiency accomplishment by minimizing the deviation from full deficiency alleviation. Programs are restricted by budget constraints and are selected according to the proportion of deficiency accomplishment they impart to deficiencies still below the set goal. Table XI summarizes the results of Formulation 5.10 with the MCDEC process data set. In general, fewer programs are required to provide the same mission deficiency accomplishment than when all programs are fully funded. Not until an extreme budget reduction is imposed does the quantity of 100 percent or greater accomplished deficiencies decreases.

TABLE XI

Results of Formulation 5.10 with MCDEC Data

Case	DA ≥ 1.00	Program Funding			Priority Changes		Deficiency Accomplishment		
	BR	Full	Part	None	DDEV	FPV	≥1.00	Part	None
A	.00	61	5	8	13	13	74	84	0
B	.10	60	6	8	14	14	74	84	0
C	.15	58	7	9	16	15	74	84	0
D	.25	53	6	15	21	20	74	84	0
E	.50	31	10	43	51	51	70	88	0

By concentrating on the number of deficiencies accomplished, formulation 5.10 identifies programs which may not be required even when funding is available. The solution values of Yj provide an identification of the deficiencies that require more RDT&E program dedication to achieve full accomplishment. Table XI case A shows that for the same deficiency accomplishment results as case I-A of Table IX only 61 programs require full funding and five need only partial funding. Case I-A of Table IX allowed 74 fully funded programs. This reduction in selected programs represents an 18.7 percent total funding reduction over the five budgeted years and a 9.9 percent funding reduction in the most restrictive year. The RDT&E programs not funded in Table XI represent those which should be reevaluated as to their extent of deficiency accomplishment prior to selection. If these programs are not selected this may lead to the recovery of resources to provide greater accomplishment of the partially alleviated deficiencies.

Unless the values of DDEV and FPV are used, formulation 5.10 does not provide a means to completly prioritize a listing of RDT&E programs. Formulation 5.10 does separate the programs into the three funding classifications of fully, partially, and not funded. If a prioritization is required, fully funded programs would logically form the highest priority and the not funded programs would form the lowest priority classification set. The partially funded programs would form the middle priority set of programs and could be further ranked within this set according to their respective funding proportion Xi.

C. DISCUSSION

Two general approachs to the MCDEC prioritization process using linear programming have been proposed. The first approach demonstrated in formulations 5.1, 5.2, 5.4, 5.5, and 5.6 maximized the MCDEC process values concerning RDT&E program relationships to mission deficiency accomplishment. Each of these formulations have an unconstrained case where they duplicate the currently proposed MCDEC process. Formulation 5.10 represents a second method to approach the MCDEC process through concentration on the quantity of deficiencies accomplished and selecting programs as needed to obtain an accomplishment goal. These approaches and formulations illustrate the feasibility and flexibility of the linear programming portfolio selection model as applied to the MCDEC process. The results listed in Tables X and XI show that for small budget reductions both approaches select programs that provide similar quantities of deficiencies accomplished but formulation 5.10 provides a less costly alternative to achieve these deficiencies.

To accept the results of any linear programming approach a major assumption must be accepted. Linear programming assumes that the relationships of coefficients and variables used in the formulation are linear or, at least, that linear functions satisfactorily approximate the actual relationships. Intuitively, and as presented in some of the literature, these interrelationships between RDT&E programs, resource expenditures, and benefits may not be linear but instead may be some other functional form. The linear functions, however, do provide an approximation to the actual situation which is understandable. The proposed formulations are possibilities which can serve as program selection tools and not as decision makers in and of themselves.

To further investigate the linearity assumptions, the relationships of the several individual coefficients and the two proportional variables should be discussed. The variables Xi and Yj which represent proportional values can both be readily accepted if their respective coefficients are proportionally divisible. In the proposed formulations, the budget constraints used the quantity [(Aki)(Xi)] to define the budget allocation to the ith program in the kth time period. The linear assumption maintains that a program funded at a proportional amount less than one will yield the same proportional benefit. In actual applications the linearity assumption may not be appropriate throughout the entire range of Xi from zero to one. Some programs may require a proportional funding lower limit greater than zero to remain a viable RDT&E program. For this condition the ith program which requires a minimum funding level could have the respective funding proportion variable Xi defined at zero and over a range from the minimum funding proportion to one. Another condition may require either full or no funding. This condition could be achieved by defining the variable Xi at the integer values of zero and one only and utilizing integer programming computations to find the optimal program selection.

A similar discussion as presented for the budget coefficient, Aki, can lead to acceptance of the linear assumptions concerning the coefficients FPVi, DDEVi, and PPDAji as they are proportionally reduced by the variable Xi. First, these coefficients must be accepted themselves as values capable of retaining their benefit measurement properties during linear programming computations. Stevens [Ref. 26] proposed the four measurement scales of nominal, ordinal, interval, and ratio which are helpful to discuss the properties of these coefficients.

Briefly, nominal scale measurements represent numerical identification for an item or event such as an auto license plate number and does not have any mathematical properties associated with it. Ordinal scale values measure rank ordering only such as the priority numbers of 1 through 74 given to the RDT&E programs as a result of the MCDEC process. Interval and ratio scales maintain a comparative worth between values. The interval scale has an established interval unit and each specific value is measured by the number of these units that separate it from other measurement values above or below it on the scale. A natural origin is not always established in an interval scale even if a zero value exists. The zero values on interval scales are assigned to arbitrary points such as on the Celsius or Fahrenheit temperature scales. Ratio scales have a natural origin in addition to the properties of the interval scales. Ratio scales are capable of proportional comparisons of the numerical values such as stating a program which costs two million dollars is twice as expensive as a one million dollar program. To maintain the same measurement properties, ratio scales can withstand multiplicative transformations only. Linear transformations can result in other ratio scales, however, the new values will be measures of a different attribute than the first.

In linear equations, values with at least interval scale properties are necessary. In linear programming, however, the coefficients require the additional properties of ratio scale measurements to withstand the ratio comparisons of coefficients and right hand side values. In Chapter IV, PPDAji is defined as a straightforward estimate of the ith program's proportion of the jth deficiency accomplishment. If these estimates are accurate, the coefficient PPDAji can be acceptable as a measurement on a ratio scale. The DDEVi coefficient is a summation of individual proportional transformations of each PPDAji based on the Deficiency Relative Importance Weight for the jth deficiency (DRIWj). The DDEVi can be accepted as a different ratio scale measurement by accepting as valid the multi-attribute utility analysis which is used to derive the DRIWj. The FPVi is a linear function of DDEVi and a Delphi process-based Subjective Evaluation Value (SEVi). DDEVi and SEVi are both adjusted by the confidence factors of the Deficiency Derived List Weight (DDLW) and the ith program's Subjective Evaluation List Weight (SELWi), respectively. Although not specifically stated by Creed, [Ref. 25], all DDEVi in the sample MCDEC data set were adjusted by a common DDLW while each SEVi was adjusted by its specific SELWi. Accepting FPVi as a different ratio measurement of RDT&E program benefit requires accepting (SEVi)(SELWi) added to (DDEVi)(DDLW). Although both FPVi and DDEVi might be accepted as ratio scale measurements of RDT&E program benefit, because of the functional change between them, they do not measure the same attributes of the ith program. The vector (SEV)(SELW) also does not represent the same qualities as the vector SEV because of the evident change of SELWi according to each program.

The MCDEC prioritization process proposed only the FPVi to represent the final relative worth of RDT&E programs in the accomplishment of mission deficiencies. If this value is acceptable then formulations 5.2 and 5.4 provide examples of linear programming portfolio selection models which will maintain an optimal program selection portfolio under budget resource reductions. If the subjective evaluation addition included in the FPVi definition is not acceptable then the multi-attribute analysis of individual deficiency importance can be included by maximizing Sum/i [(DDEVi)(Xi)] as in formulations 5.5 and 5.6. These formulations allow program selection solutions under budget reductions which may not be obtained through priority listings only. The last formulation approach, which does not directly represent the currently proposed MCDEC process, appears to be a favorable RDT&E program selection model as shown from the example data set. Formulation 5.10 provides identification of programs requiring reevaluation, deficiencies requiring dedicated programs, and a selection of programs that accomplish the maximum deficiency alleviation. It should be noted that in all the proposed linear program formulations the solutions are optimal computations of the benefit and coefficient data provided and can only be given the confidence inherent in the data themselves.

VI. CONCLUSIONS

A. RESULTS

This thesis has investigated the MCDEC Prioritization Process. This process was produced by the Development Center, MCDEC, to establish the relative importance of RDT&E programs prior to Marine Corps input to the RDT&E,N POM. An investigation of the literature showed that the MCDEC process can be classified with similar benefit measurement models currently accepted by industry. The literature also identified other proposed and accepted RDT&E program selection models, classified as portfolio selection models, which showed possible advantages that could enhance the proposed MCDEC process. Several MCDEC process linear programming model modifications were presented and showed the portfolio selection model advantages of maximizing the benefit function when subjected to resource constraints.

The feasibility of representing the MCDEC process as a linear programming portfolio selection model was illustrated. These illustrations raised the possibility that the Final Program Value assigned in the process might not be the best measurement of RDT&E program mission deficiency accomplishment. Another linear programming model approach to selecting the RDT&E programs, represented by the example data, was also illustrated and provided an economical alternative for maximizing deficiency accomplishment.

Currently a mathematical analysis support model is used as a tool in the Procurement Marine Corps POM process but not in the development of the Marine Corps portion of the RDT&E,Navy POM. According to the literature, industry accepts the use of subjective input with analytic tools for

RDT&E program selection applications. The MCDEC process as it stands or with the portfolio selection enhancements has a base to assist as an analytic tool for the Marine Corps responsibilities in the RDT&E,N POM process.

B. FURTHER INVESTIGATIONS

Several areas of further study and research are evident from this investigation. The variety of program selection models proposed in the literature each have advantages and disadvantages which require further investigation as to their possible application to the Marine Corps RDT&E program selection process. The data gathering and compiling techniques of these additional models require study as well as a complete analysis of the data and process results from a complete trial MCDEC process run. The most difficult further research will be to estimate the model costs and perform a cost benefit analysis of implementing a RDT&E program selection model process.

The literature review chapter presented model evaluation criteria and limitations suggested for industrial R&D program selection models. Further research is required into the applications of these or similar criteria and limitations in the context of Marine Corps applications specifically. The extent of industrial model applications to the Marine Corps will be limited because of the non-profit orientation of defense. However, the other portfolio selection models reviewed in the literature may provide valuable alternatives to the presented MCDEC linear programming model.

Subjective evaluation of RDT&E programs was seen accepted as a necessity in the literature and was seen proposed for use in the MCDEC process. The manipulation of the subjective data by the MCDEC process was discussed here in context of measurement scale properties. Further investigation into the subjective values and their true measurements is needed. Saaty [Ref. 24] and Lindsay [Ref. 27] have proposed different methods of combining subjective judgements into quantities that maintain measurement scale properties. Further investigation into these or other subjective judgement methods may provide more acceptable alternatives than the Delphi and value manipulation methods currently proposed.

Formulation 5.4 illustrated the possible resource allocation advantages from assigning a proportional program funding variable to each year in the planning horizon. The benefit received from the programs, however, may also change over time. Further study is necessary to investigate the program benefit measurement values used in the portfolio selection models and how these values change over time. Additional variables and benefit coefficients necessary to describe each time period will increase the computer storage and computational requirements and this increase will also need investigation.

The costs and benefits of implementing the proposed process also requires further study. The current process software was developed for a Tectronix 4054 minicomputer and is not compatible on other systems. Resources in terms of manhours and money will be required to upgrade or reprogram process software to ensure compatibility with mircocomputer systems currently at HQMC and the Development Center. The presented linear programming computations utilized a Ketron, Inc. MPSIII Dataform package as run on an IBM 3033 computer. Further investigation into microcomputer linear programing software is necessary and represents additional costs. If large linear programing packages are required to enhance the process additional mainframe usage will add costs. Gathering the subjective data from operational and non-operational units during the MCDEC process survey analysis represents manpower and TAD costs not currently required. The total monetary benefits are possibly the hardest to classify or estimate. The value of valid information concerning new defense systems and programs as they affect the mission accomplishment of the Marine Corps will need further research to quantify.

APPENDIX A
MCDEC PRIORITIZATION PROCESS

This appendix displays the organizational structure for the Development Center, Deputy Chief of Staff for Developmental Coordination, Prioritization Working Group; and Chief of Staff's Prioritization Committee in Figures A.1, A.2, A.3, and A.4 respectively. The remainder of the appendix details the phases and tasks of the MCDEC prioritization process and lists the specific Development Center agency responsible for completing each step. The purposes for each following tasks are quoted from Creed [Ref. 25].

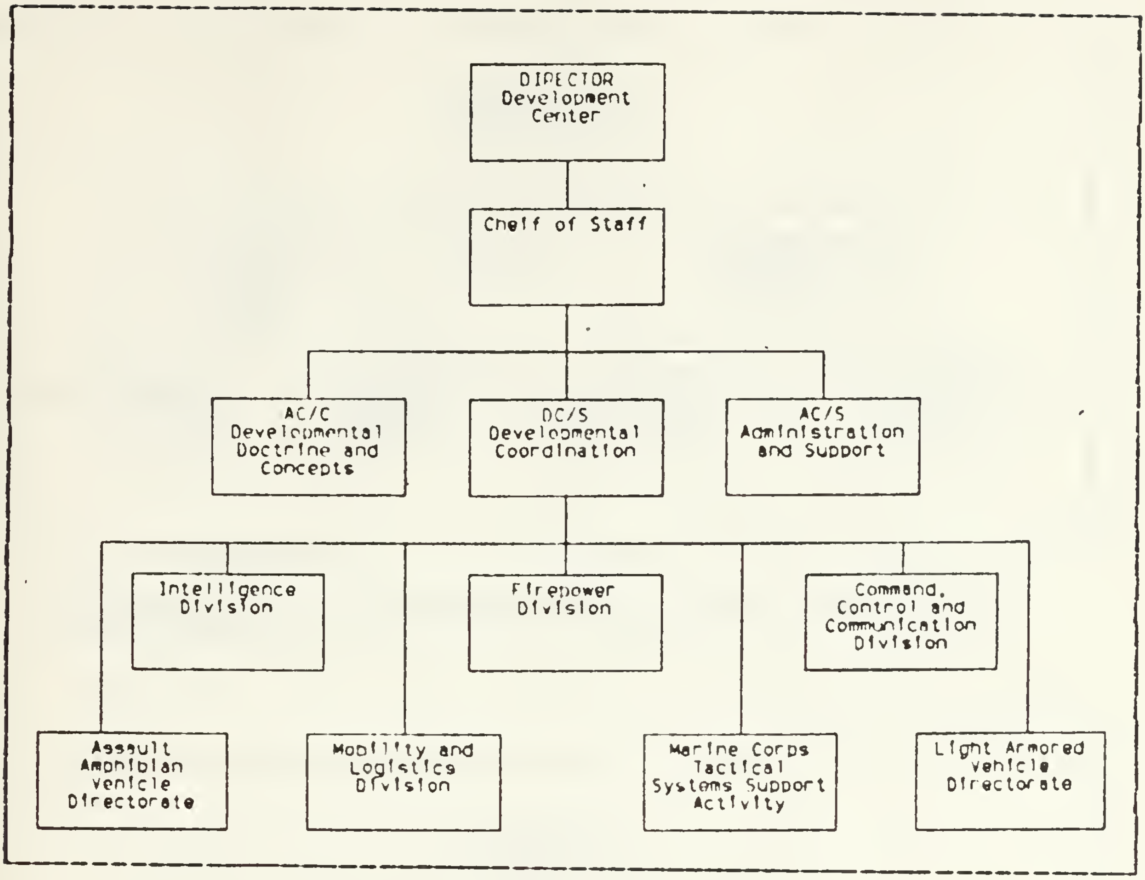
DIRECTOR Development Center
Cheif of Staff
AC/C Developmental Doctrine and Concepts
DC/S Developmental Coordination
AC/S Administration and Support
Intelligence Division
Firepower Division
Command, Control and Communication Division
Assault Amphibian Vehicle Directorate
Mobility and Logistics Division
Marine Corps Tactical Systems Support Activity
Light Armored Vehicle Directorate

Figure A.1 Development Center Structure.

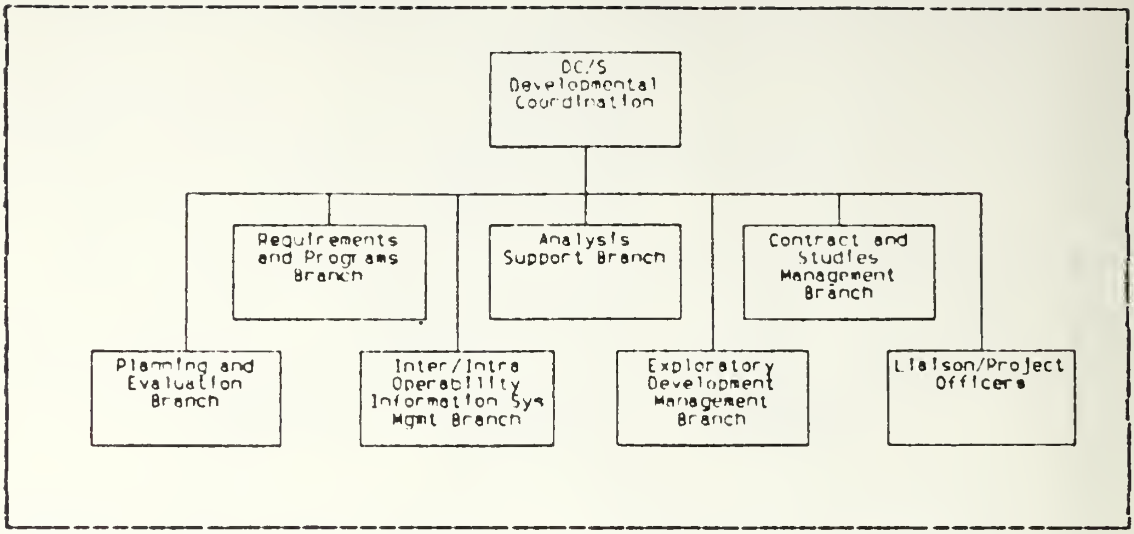
DC/S Developmental Coordination
Requirements and Programs Branch
Analysis Support Branch
Contract and Studies Management Branch
Planning and Evaluation Branch
Inter/Intra Operability Information Sys Mgmt Branch
Exploratory Development Management Branch
Liaison/Project Officers

Figure A.2 Developmental Coordination Structure.

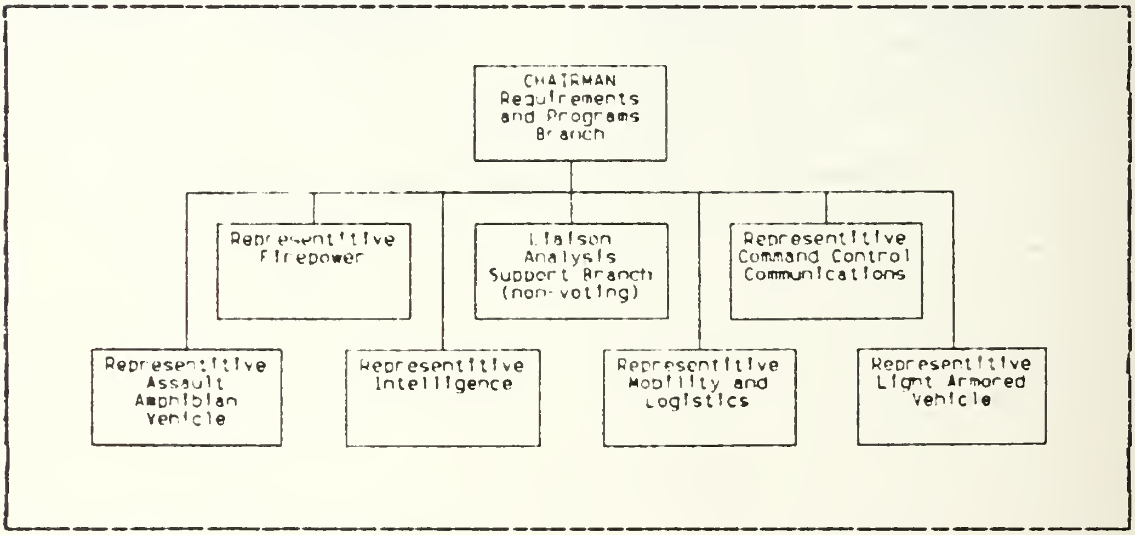
CHAIRMAN Requirements and Programs Branch
Representitive Firepower
Liaison Analysis Support Branch (non-voting)
Representitive Command Control Communications
Representitive Assault Amphibian Vehicle
Representitive Intelligence
Representitive Mobility and Logistics
Representitive Light Armored Vehicle

Figure A.3 Pricritization Working Group Structure.

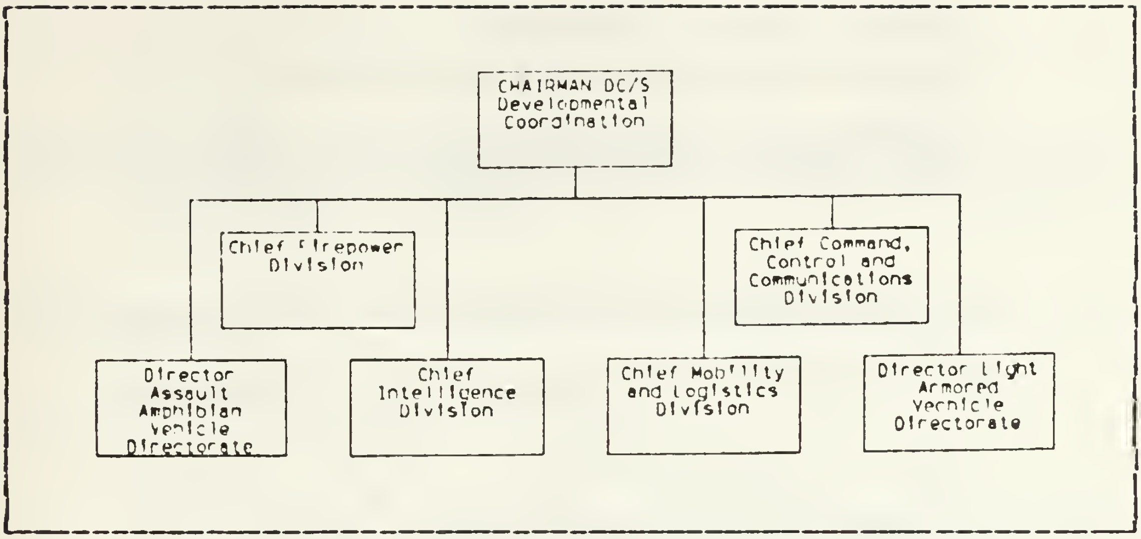

Figure A.4 Prioritization Committee Structure.

A. Phase I: Determine deficiencies and requirements,

Task 1. Preparation of plans

Dates: 1 January to 28 February

Agency: Planning and Evaluation Branch

Purpose: To provide an approved basis, via guidance and direction set forth in Marine Corps plans, for subsequent Mission Area Analyses, by updating and/or revision of basic Marine Corps planning documents - i.e., MMROP and MLRP.

Task 2. Survey Analyses

Dates: 1 January to 30 March

Agency: Analysis Support Branch

Purpose: To gather opinion input from FMF and other appropriate commands/agencies regarding the effectiveness of ongoing projects in the R&D program and to solicit new program ideas.

Task 3. Mission Area Analyses

Dates: 1 March to 30 April

Agency: Planning and Evaluation Branch

Purpose: To provide the basis for justification of R&D projects via specified Marine Corps deficiencies resulting from Mission Area Analysis.

B. Phase II: Prioritize deficiencies and requirements,

Task 1. Mission Area Analysis Results Briefings

Dates: 1 May to 15 May

Agency: Planning and Evaluation Branch

Purpose: To provide the Prioritization Working Group (PRWG) with Mission Area Element(s) deficiencies-oriented briefings in preparation for the PRWG MAA prioritizations (Phase II Task 2).

Task 2. Survey Analysis Results Briefings

Dates: 1 May to 15 May

Agency: Analysis Support Branch

Purpose: To provide the Prioritization Working Group (PRWG) with FMF/major command and agency derived input obtained during Phase I, concerning deficiencies.

Task 3. Design of the Deficiency decision tree

Dates: 15 May to 15 July

Agency: Prioritization Working Group (PRWG)

Purpose: To analytically derive, vis multi-attribute utility analysis, a consolidated rank-ordering af all Mission Area (element) deficiencies and an associated relative importance weight of each.

C. Phase III: Prioritize R&D programs,

Task 1. Program Project briefings

Dates: 15 July to 15 August

Agency: Division DPO's (scheduled by Operations Branch)

Purpose: To provide preparatory information to the Prioritization Working Group and Chief of Staff's Committee for consideration in subsequent prioritization deliberations.

Task 2. Survey Analysis Results Briefing

Dates: 15 July to 15 August

Agency: Analysis Support Branch

Purpose: To provide preparatory information derived from FMF/major commands or agencies to the Prioritization Working Group and Chief of Staff's Committee for consideration in subsequent prioritization deliberations.

Task 3. Subjective Prioritization of R&D Program Projects

Dates: 15 August to 1 October

Agency: Analysis Support Branch

Purpose: To obtain a subjective prioritization of R&D Projects with associated weighted values of each reflecting relative worth.

Task 4. Deficiency-Derived Prioritization of R&D Projects

Dates: 15 August to 1 October

Agency: Prioritization Working Group (PRWG)

Purpose: To obtain a prioritization of R&D program projects ranked and weighted according to that project's capability to overcome Mission Area Element deficiencies.

Task 5. Final Prioritization of R&D projects

Dates: 1 October to 15 October

Agency: Prioritization Working Group (PRWG)

Purpose: To obtain a final prioritization of R&D program projects from the subjective-derived list and deficiency-derived list combined.

Task 6. Director Development Center, Decision Brief for Action

Dates: 15 October to 31 October

Agency: As Directed

Purpose: To present the recommended R&D program project priority for decision.

D. Phase IV: Complete MCDEC R & D programs list in HQMC POM.

Task 1. Application of funding profiles

Dates: 1 November to 31 December

Agency: Operations Branch

Purpose: To determine recommended funding profiles to reflect the desired prioritization of R&D Program Projects.

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